



La-Net

AGE 308

FISH FARMING AND MANAGEMENT



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INSTITUTION STUDENTS

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Series 1: Foundations of Fisheries and Aquaculture

- **Part 1.1: Definitions and Scope of Fisheries and Aquaculture**
 - Sub Part 1.1.1: Definitions and key concepts
 - Sub Part 1.1.2: Scope and branches of fisheries science
 - Sub Part 1.1.3: Differences between capture fisheries and aquaculture
- **Part 1.2: Importance of Fisheries and Aquaculture in Nigeria**
 - Sub Part 1.2.1: Nutritional and food security importance
 - Sub Part 1.2.2: Economic and livelihood importance
 - Sub Part 1.2.3: The fish industry in Nigeria
- **Part 1.3: Fisheries Resources of West Africa and Nigeria**
 - Sub Part 1.3.1: Freshwater fisheries resources
 - Sub Part 1.3.2: Marine and coastal fisheries resources
 - Sub Part 1.3.3: Important fish species of Nigeria
- **Part 1.4: Principles and Policy Framework of Fisheries Management**
 - Sub Part 1.4.1: Fundamental principles of fisheries management
 - Sub Part 1.4.2: Fisheries legislation and policy in Nigeria
 - Sub Part 1.4.3: International fisheries agreements and conventions



Introduction

Fish is the most important single source of animal protein in the Nigerian diet, supplying approximately 40 per cent of total animal protein consumed by the population. Yet Nigeria imports hundreds of thousands of tonnes of fish annually to bridge the gap between domestic production and demand, at a foreign exchange cost that runs into billions of naira. Understanding the foundations of fisheries science and aquaculture is the essential starting point for addressing this deficit and for equipping students with the knowledge to contribute to national food security through productive fish farming and responsible resource management.

This Series introduces the definitions, scope, and branches of fisheries science and aquaculture, distinguishes between capture fisheries and aquaculture, explains the nutritional, economic, and industrial importance of fisheries in Nigeria, surveys the freshwater and marine fisheries resources of West Africa and Nigeria, and covers the fundamental principles and policy framework of fisheries management. All subsequent Series build on these foundations.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 1.1** define fisheries and aquaculture and explain the key concepts of each (Linked to Part 1.1),
- **SLO 1.2** describe the scope and main branches of fisheries science (Linked to Part 1.1),
- **SLO 1.3** distinguish between capture fisheries and aquaculture and explain the advantages of each (Linked to Part 1.1),
- **SLO 1.4** explain the nutritional importance of fish in Nigeria and describe its contribution to food security (Linked to Part 1.2),
- **SLO 1.5** describe the economic importance of fisheries and the structure of the fish industry in Nigeria (Linked to Part 1.2),
- **SLO 1.6** identify the major freshwater and marine fisheries resources of West Africa and Nigeria (Linked to Part 1.3),



- **SLO 1.7** name the important fish species of Nigeria and state their habitat, distribution, and economic value (Linked to Part 1.3), and
- **SLO 1.8** explain the fundamental principles and policy framework of fisheries management in Nigeria (Linked to Part 1.4).

1.1 Definitions and Scope of Fisheries and Aquaculture

1.1.1 Definitions and key concepts

Fisheries is the science and practice concerned with the harvesting, management, and conservation of fish and other aquatic organisms from their natural environments (oceans, rivers, lakes, and estuaries). It encompasses the biological study of fish populations, the technology of fish capture, and the economic and social dimensions of fishing communities. Aquaculture is the controlled cultivation of aquatic organisms (fish, shellfish, crustaceans, molluscs, and aquatic plants) in freshwater, brackish water, or marine environments, analogous to agriculture on land; it involves deliberate intervention in the rearing process to increase production above what natural environments would yield.

Related key concepts include: fish stock (a population of fish of one species in a defined area that is managed as a unit); sustainable yield (the quantity of fish that can be harvested repeatedly over time without depleting the stock); maximum sustainable yield (MSY, the largest average catch that can be harvested from a stock under prevailing environmental conditions on a sustainable basis); by-catch (non-target organisms unintentionally caught during fishing operations); and aquatic biodiversity (the variety of species, genetic diversity, and ecosystem diversity in aquatic environments). These concepts underpin all subsequent topics in the course.

Fill in the blank: Aquaculture is the controlled cultivation of aquatic organisms in fresh, brackish, or marine water, analogous to agriculture on land; it involves deliberate _____ in the rearing process to increase production above natural yields.



1.1.2 Scope and branches of fisheries science

Fisheries science is multidisciplinary, drawing on biology, ecology, oceanography, limnology, engineering, economics, and social science. The major branches are: fish biology (anatomy, physiology, behaviour, and life history of fish); fisheries ecology (the interaction of fish populations with their biotic and abiotic environment); fisheries stock assessment (the quantitative evaluation of fish stock size, growth, mortality, and reproductive rate to support management decisions); fishing technology (the design and operation of fishing gear, vessels, and navigation systems); aquaculture (controlled fish and shellfish rearing); fish processing and preservation (methods for maintaining fish quality from catch to consumer); and fisheries economics and management (economic analysis of fishing industries and the governance of fisheries resources).

In Nigeria, fisheries science is taught and practised in university departments of aquaculture and fisheries management, at the Nigerian Institute for Oceanography and Marine Research (NIOMR) in Lagos, at the National Institute for Freshwater Fisheries Research (NIFFR) in New Bussa, and at several state fisheries departments. The Federal Department of Fisheries (FDF) under the Federal Ministry of Agriculture and Rural Development coordinates national fisheries policy, stock assessment, and extension services.

Fill in the blank: The two major national research institutes for fisheries in Nigeria are NIOMR (marine research) in Lagos and _____ (freshwater fisheries research) in New Bussa.

1.1.3 Differences between capture fisheries and aquaculture

Capture fisheries harvest fish from their natural habitats using nets, traps, lines, and other fishing gear. The fish are wild, the breeder does not control reproduction or feeding, and the quantity that can be harvested is limited by the natural productivity of the water body. In Nigeria, capture fisheries operate on the Atlantic Ocean coast, in inland rivers (Niger, Benue, Cross River, Sokoto-Rima), and in natural and man-made lakes (Lake Chad, Kainji, Jebba, Shiroro, and Tiga). Capture fisheries production in Nigeria is estimated at approximately 600,000 to 800,000 metric tonnes per year but has been declining due to overfishing and environmental degradation.



Aquaculture grows fish under controlled conditions in ponds, tanks, cages, or raceways. The farmer controls stocking density, feeding, water quality, and reproduction, enabling yields far higher than natural water bodies. Aquaculture has been the fastest-growing food production sector globally for three decades, now supplying approximately 50 per cent of world fish consumed. In Nigeria, aquaculture (primarily catfish and tilapia farming) has expanded rapidly since the 1990s and currently produces approximately 300,000 to 400,000 metric tonnes per year, still far short of national demand. The deficit is bridged by imports, predominantly frozen mackerel (*Scomber japonicus*) and herrings.

Fill in the blank: Nigeria's capture fisheries produce approximately 600,000 to 800,000 metric tonnes per year but have been declining due to _____ and environmental degradation; aquaculture produces approximately 300,000 to 400,000 metric tonnes per year.

<u>Aspect</u>	<u>Capture Fisheries</u>	<u>Aquaculture</u>
Environment	Natural water bodies (rivers, lakes, reservoirs, coastal waters)	Artificial ponds, tanks, cages, controlled systems
Production Control	Very limited; dependent on natural stock and ecosystem	High; stocking density, water quality, and management controlled
Feeding	Natural food sources (plankton, aquatic plants, smaller fish)	Supplementary or complete formulated feeds provided
Reproduction	Natural spawning in wild habitats	Induced breeding, controlled spawning, hatchery management
Nigerian Species	Tilapia, catfish, bonga, croaker	African catfish (<i>Clarias gariepinus</i>), tilapia, <i>Heterobranchus</i> spp.
Yield	Variable, often declining due to overfishing	Predictable, higher per unit area under good management
Sustainability	Threatened by overfishing, pollution, habitat loss	More sustainable if managed well, but requires inputs and monitoring

Table 1.1: Comparison of capture fisheries and aquaculture

Pilot questions 1.1

1. Define fisheries and aquaculture and explain how they differ.



2. Define maximum sustainable yield (MSY) and explain its importance in fisheries management.
3. Name four branches of fisheries science and briefly describe each.
4. State two national institutions responsible for fisheries research in Nigeria and their locations.
5. State three advantages of aquaculture over capture fisheries for Nigerian food production.

1.2 Importance of Fisheries and Aquaculture in Nigeria

1.2.1 Nutritional and food security importance

Fish provides high-quality animal protein, essential fatty acids (especially omega-3 polyunsaturated fatty acids, EPA and DHA), vitamins (A, D, B12), and minerals (iodine, selenium, zinc, calcium in small dried fish). In Nigeria, fish contributes approximately 40 per cent of total animal protein intake and is the most affordable source of animal protein for the majority of the population, including low-income urban and rural households. Dried, smoked, and fermented fish products (stockfish, bonga, eja gbigbe, asa dried) are particularly important as affordable protein sources traded widely across all regions of the country.

Fish consumption is critical for food security among vulnerable groups: children (for growth and brain development, particularly the omega-3 fatty acids DHA and EPA), pregnant and lactating women (for fetal and infant development), and the elderly (for muscle maintenance). In communities along the Niger and Benue rivers, Lake Chad, and the Niger Delta, fish may provide 50 to 70 per cent of total protein intake. The current annual fish demand in Nigeria is estimated at approximately 3.5 million metric tonnes against domestic supply of approximately 1 million metric tonnes; the remaining 2.5 million metric tonnes is imported at a foreign exchange cost of approximately USD 1.5 billion per year.

Fill in the blank: Fish contributes approximately _____ per cent of total animal protein intake in Nigeria and is the most affordable source of animal protein for the majority of the population.



1.2.2 Economic and livelihood importance

The fisheries sector contributes approximately 1.5 to 2 per cent of Nigeria's GDP and employs over 8 million people directly in fishing, aquaculture, fish processing, and trading. Artisanal fishing communities along the coast and inland waters depend entirely on fisheries for their livelihoods. Fish trading (particularly by women fish traders called "mama fish" or "iya eja") is a major source of income for millions of women in fishing communities. Aquaculture has created new employment opportunities in catfish and tilapia farming, feed manufacturing, fingerling production, and equipment supply.

The fisheries sector also generates foreign exchange: export of dried crayfish (*Penaeus* spp. and *Nematopalaemon hastatus*), dried catfish, smoked bonga, and sea cucumber generates some revenue, though Nigeria is a net fish importer. Catfish farming has expanded into a significant agribusiness sub-sector in south-western Nigeria, with large-scale commercial farms producing hundreds of tonnes per annum and supplying restaurants, supermarkets, and processing facilities. The value chain of the catfish industry includes broodstock management, hatchery operations, nursery and grow-out farming, feed production, processing, and marketing.

Fill in the blank: The Nigerian fisheries sector employs over _____ million people directly in fishing, aquaculture, processing, and trading, contributing approximately 1.5 to 2 per cent of GDP.

1.2.3 The fish industry in Nigeria

The Nigerian fish industry has three major sub-sectors: the artisanal (small-scale) fisheries sub-sector (employing the majority of fishers using dug-out canoes, wooden planked boats, and traditional gear on rivers, lakes, estuaries, and coastal waters); the industrial fisheries sub-sector (using trawlers and purse-seiners operating in the Exclusive Economic Zone of the Atlantic Ocean, owned mainly by large companies with government concessions); and the aquaculture sub-sector (including catfish and tilapia farms ranging from backyard pond operations to large commercial farms with controlled environments, recirculating aquaculture systems, and cage culture on reservoirs).



Fish processing in Nigeria includes smoking (the most common method, using traditional clay ovens, steel drums, and improved Chorkor smokers), sun drying, salting, and fermentation (to produce iru and ogiri type products from bonga). Refrigeration and freezing chains remain inadequate in many areas, contributing to post-harvest losses estimated at 20 to 35 per cent of catch. The Federal Government's programmes to develop the fisheries sector include the establishment of fish processing zones, provision of fishing vessels and gear through the Presidential Initiative on Increased Fish Production, and support for aquaculture through the Agricultural Transformation Agenda.

Fill in the blank: The three major sub-sectors of the Nigerian fish industry are artisanal fisheries, _____ fisheries (using trawlers and purse-seiners in the EEZ), and aquaculture.

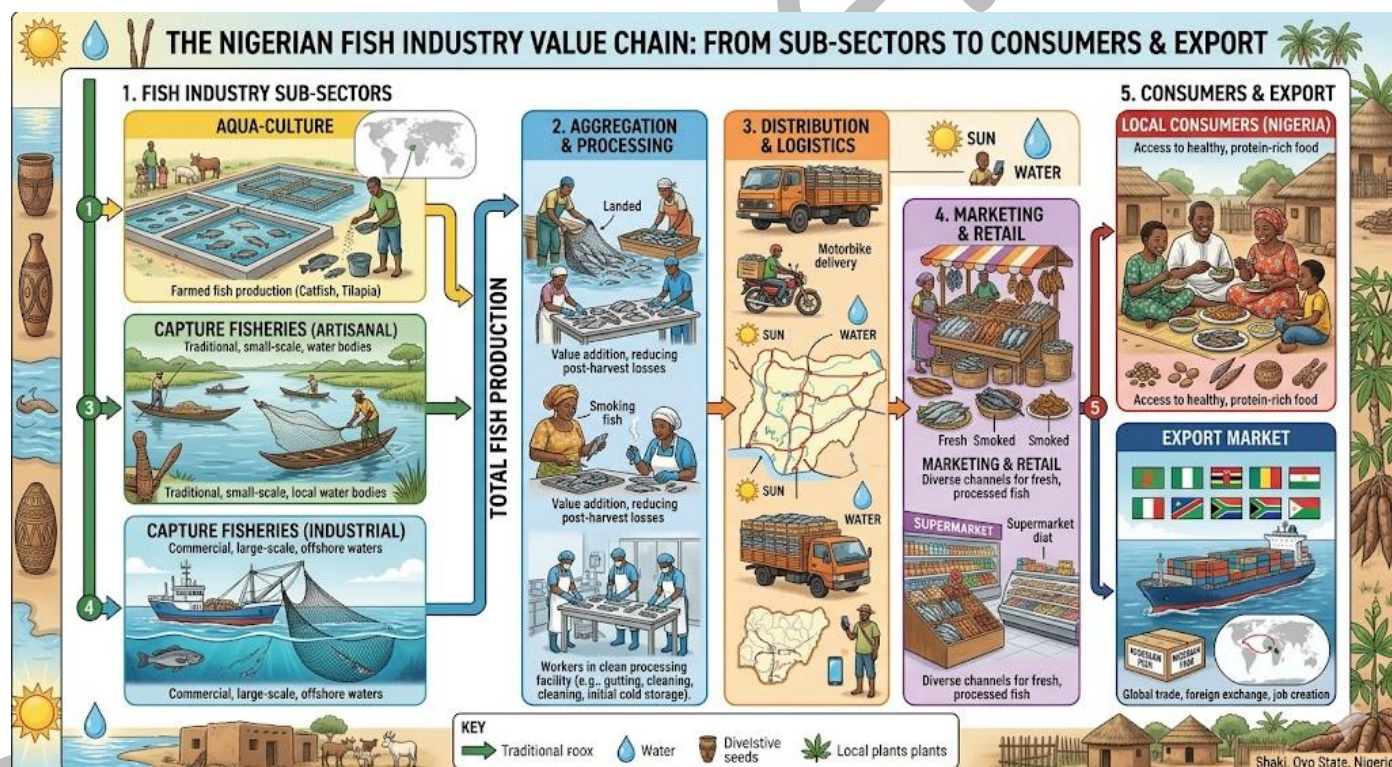


Figure 1.1: Diagram showing the three sub-sectors and value chain of the Nigerian fish industry

Pilot questions 1.2

1. State three nutritional benefits of fish consumption for vulnerable groups in Nigeria.
2. Explain why the current fish supply-demand gap in Nigeria is a food security concern.
3. State the contribution of the fisheries sector to Nigerian GDP and employment.



4. Describe the three sub-sectors of the Nigerian fish industry.
5. Explain why post-harvest losses are high in Nigerian fisheries and state one measure to reduce them.

1.3 Fisheries Resources of West Africa and Nigeria

1.3.1 Freshwater fisheries resources

Nigeria has an estimated 12.5 million hectares of inland water bodies, including rivers, lakes, reservoirs, floodplains, and wetlands. The major river systems are the Niger-Benue system (the largest, draining approximately two-thirds of the country), the Cross River, the Anambra, the Osun, the Ogun, the Hadejia-Jama'are-Komadugu-Yobe, and the Sokoto-Rima. Major natural lakes include Lake Chad (shared with Niger, Cameroon, and Chad; severely reduced in area from 25,000 km² in 1963 to approximately 1,500 km² today due to climate change and water abstraction). Major reservoirs include Kainji, Jebba, Shiroro (Niger State), Tiga (Kano), Goronyo (Sokoto), Bakolori, and Challawa Gorge.

The major freshwater fish families exploited in Nigerian rivers and lakes are: Cyprinidae (carps and minnows); Mormyridae (elephantfish); Characidae (tetras, tiger fish); Clariidae (catfishes, particularly *Clarias gariepinus* and *Heterobranchus* spp.); Cichlidae (tilapias, *Oreochromis niloticus* and *Tilapia zillii*); Osteoglossidae (*Heterotis niloticus*, the Nile arowana); Polypteridae (bichirs); and Schilbeidae (*Schilbe* spp.). The Niger-Benue system supports the greatest diversity and abundance of freshwater fish in Nigeria, with over 200 species recorded.

Fill in the blank: Nigeria's estimated inland water body area is approximately _____ million hectares; the largest river system is the Niger-Benue, draining approximately two-thirds of the country.

1.3.2 Marine and coastal fisheries resources

Nigeria has approximately 853 km of Atlantic Ocean coastline, an Exclusive Economic Zone (EEZ) of about 200 nautical miles, and extensive coastal ecosystems including mangrove forests,



estuaries, lagoons, and the Niger Delta. The coastal and marine environment supports diverse fisheries: demersal fish (bottom-dwelling species such as croakers, snappers, groupers, and sea breams fished by trawlers on the continental shelf); pelagic fish (open-water schooling species such as bonga (*Ethmalosa fimbriata*), mackerel (*Scomber japonicus*), sardinellas (*Sardinella* spp.), and flying fish (*Exocoetus* spp.) fished by purse-seiners and lift nets); and benthic invertebrates (shrimps, crabs, and crayfish fished in estuaries and coastal waters).

The Gulf of Guinea is one of the most productive marine environments in Africa, influenced by seasonal upwellings of cold, nutrient-rich water along the coast of Benin and Nigeria. Nigeria shares these resources with neighbouring countries: Benin, Togo, Ghana, and Cameroon.

Overfishing of demersal stocks on the Nigerian continental shelf has been documented since the 1970s; industrial trawling has depleted bottom-fish populations and damaged benthic habitats.

The artisanal coastal fishery, using dugout canoes, plank boats, gill nets, seine nets, and cast nets, exploits the pelagic and estuarine species more sustainably.

Fill in the blank: Nigeria's Atlantic coastline extends approximately _____ km with an Exclusive Economic Zone of about 200 nautical miles; the Gulf of Guinea is a highly productive marine environment influenced by seasonal coastal upwellings.



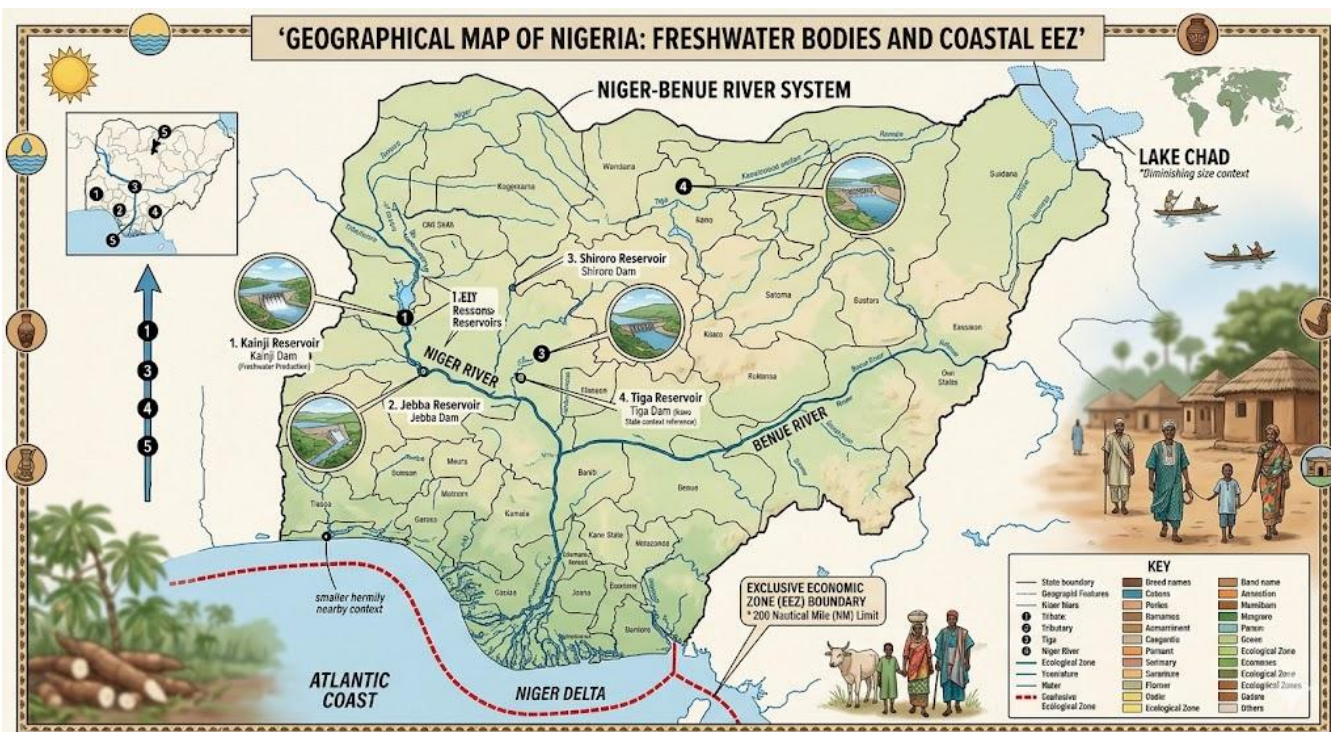


Figure 1.2: Map of Nigeria showing major freshwater bodies and the coastal EEZ

1.3.3 Important fish species of Nigeria

The most economically important fish species in Nigeria include: African catfish (*Clarias gariepinus*) and the sharptooth catfish (*Clarias angustifrons*): the primary species in Nigerian aquaculture, hardy, fast-growing, air-breathing, and commanding high market prices; Nile tilapia (*Oreochromis niloticus*): the second most farmed species, omnivorous, fast-growing, and widely accepted in southern Nigerian markets; bonga shad (*Ethmalosa fimbriata*): the most important artisanal marine species, caught in huge quantities along the coast and smoked; Nile perch (*Lates niloticus*): a large predatory freshwater species from Lake Chad and the Niger; and crayfish (*Nematopalaemon hastatus* and *Penaeus* spp.): small shrimps and prawns from the Niger Delta and coastal estuaries, sun-dried and traded as a flavouring throughout Nigeria.

Other important species include: *Heterobranchius longifilis* and *H. bidorsalis* (catfishes farmed alongside *Clarias*); *Heterotis niloticus* (the Nile arowana or giant gourami, a large food fish of the Niger-Benue floodplain); *Gymnarchus niloticus* (the aba aba or knifefish, smoked and traded as eja osan); *Synodontis* spp. (upside-down catfishes from rivers); sardinellas (*Sardinella*



maderensis and *S. aurita*, coastal pelagics); and cichlid species in the genus *Tilapia* and *Hemichromis* (jewel fish). In West Africa generally, barbus (*Barbus* spp.), labeo (*Labeo* spp.), and tigerfish (*Hydrocynus vittatus*) are also important artisanal fishery species.

Fill in the blank: The two most important species in Nigerian aquaculture are African catfish (*Clarias gariepinus*) and Nile tilapia (_____ niloticus); the most important artisanal marine species is bonga shad (*Ethmalosa fimbriata*).

<u>Common Name</u>	<u>Scientific Name</u>	<u>Habitat</u>	<u>Primary Economic Use</u>
African Catfish	<i>Clarias gariepinus</i>	Rivers, lakes, ponds, aquaculture systems	Aquaculture, commercial food fish
Tilapia	<i>Oreochromis niloticus</i>	Rivers, reservoirs, ponds	Aquaculture, artisanal fisheries
Bonga Shad	<i>Ethmalosa fimbriata</i>	Coastal waters, estuaries	Artisanal fisheries, smoked/dried fish trade
Nile Perch	<i>Lates niloticus</i>	Large rivers and lakes	Commercial fisheries, export potential
Croaker	<i>Pseudotolithus elongatus</i>	Marine and estuarine waters	Coastal fisheries, fresh and smoked fish markets
Heterobranchus Catfish	<i>Heterobranchus bidorsalis</i>	Rivers, floodplains, aquaculture	Aquaculture, hybrid breeding with <i>Clarias</i>
Sardine (West African)	<i>Sardinella maderensis</i>	Marine waters (Atlantic coast)	Coastal fisheries, canned fish industry

Table 1.2: Important fish species of Nigeria with their habitat and economic importance

Pilot questions 1.3

1. Name the five major river systems of Nigeria and identify the largest.
2. State the current approximate area of Lake Chad and explain the main causes of its reduction.
3. Distinguish between demersal and pelagic fish and give two Nigerian examples of each.
4. Name the two most important aquaculture species in Nigeria and state three characteristics of each.
5. Explain the economic importance of crayfish to Nigeria.



1.4 Principles and Policy Framework of Fisheries Management

1.4.1 Fundamental principles of fisheries management

Fisheries management is the deliberate process of regulating human activities in relation to fish stocks and aquatic ecosystems to achieve defined biological, economic, and social objectives. The fundamental principles of fisheries management are: the precautionary principle (in the absence of adequate scientific information, management decisions should err on the side of conservation to avoid irreversible depletion); ecosystem-based management (managing fisheries within the context of the whole ecosystem, considering the effects of fishing on non-target species, habitats, and ecological processes); maximum sustainable yield (MSY) as a management reference point; and adaptive management (adjusting management measures as new scientific information becomes available).

Management tools include: catch limits (total allowable catch, TAC, set below MSY); size limits (minimum legal fish size to protect juveniles before they reproduce); closed seasons (periods during which fishing is prohibited to protect spawning aggregations); closed areas (spatial closures to protect critical habitats, nursery areas, and spawning grounds); gear regulations (prohibition or modification of destructive gears such as poison, explosives, fine-mesh nets, and electric fishing); licensing (controlling the number of fishing vessels and gears); and aquaculture development (as an alternative to increasing pressure on capture stocks).

Fill in the blank: The _____ principle states that in the absence of adequate scientific information, management decisions should err on the side of conservation to avoid irreversible stock depletion.

1.4.2 Fisheries legislation and policy in Nigeria

The principal fisheries legislation in Nigeria is the Fisheries Act (Cap F10, Laws of the Federation of Nigeria 2004), which regulates fishing in Nigerian waters, controls the use of destructive fishing methods, establishes a licensing system for fishing vessels, and empowers the



Federal Department of Fisheries to enforce regulations. The Sea Fisheries Act controls trawling operations in the EEZ. The National Policy on Marine Fisheries and Aquaculture Development (2015) sets the strategic direction for increasing domestic fish production through artisanal fisheries improvement, aquaculture expansion, and reduction of post-harvest losses.

Institutional responsibilities are shared: the Federal Department of Fisheries (FDF) under the Federal Ministry of Agriculture oversees national fisheries policy, stock assessment, and enforcement; state fisheries departments manage inland fisheries within state jurisdictions; NIOMR conducts marine fisheries research; NIFFR conducts freshwater fisheries research. The Fisheries Society of Nigeria (FISON) is the major professional association. Challenges in enforcement include inadequate patrol vessels, corruption, the artisanal nature of most fishing, and the vast extent of inland waters to be monitored.

Fill in the blank: The principal fisheries legislation in Nigeria is the Fisheries _____ (Cap F10, Laws of the Federation of Nigeria 2004), which regulates fishing, controls destructive methods, and establishes a licensing system.

1.4.3 International fisheries agreements and conventions

Nigeria participates in several international fisheries agreements and conventions. The United Nations Convention on the Law of the Sea (UNCLOS, 1982) establishes the 200-nautical-mile Exclusive Economic Zone within which coastal states have sovereign rights over living marine resources. The Code of Conduct for Responsible Fisheries (CCRF, FAO 1995) provides guidelines for sustainable fishing, aquaculture development, fisheries research, fish trade, and coastal management. The Convention on Biological Diversity (CBD, 1992) addresses the conservation of aquatic biodiversity, including fish species and their ecosystems.

At the regional level, Nigeria cooperates with West African neighbours through the Fishery Committee for the Eastern Central Atlantic (CECAF), which provides scientific advice for the management of shared stocks in the Gulf of Guinea. The Lake Chad Basin Commission (LCBC) coordinates the management of Lake Chad fisheries among Nigeria, Niger, Cameroon, and Chad. FAO provides technical assistance through its Fisheries and Aquaculture Department, supporting stock assessment, aquaculture development, and policy reform in Nigeria. Illegal, unreported,



and unregulated (IUU) fishing by foreign vessels in Nigerian waters remains a major challenge, depriving the country of significant fisheries resources.

Fill in the blank: The UN Convention on the Law of the Sea (UNCLOS) establishes the 200-nautical-mile _____ Economic Zone within which coastal states have sovereign rights over living marine resources.

<u>Agreement</u>	<u>Relevance to Nigeria</u>
United Nations Convention on the Law of the Sea (UNCLOS)	Defines Nigeria's Exclusive Economic Zone (EEZ) rights and responsibilities for marine resource management.
FAO Code of Conduct for Responsible Fisheries	Provides global guidelines for sustainable fishing practices, adopted in Nigeria's fisheries policy framework.
Convention on Biological Diversity (CBD)	Ensures conservation of aquatic biodiversity, relevant to Nigeria's inland and coastal ecosystems.
CITES (Convention on International Trade in Endangered Species)	Regulates trade in endangered aquatic species, affecting Nigeria's export of certain fish and aquatic products.
West African Sub-Regional Fisheries Commission (SRFC)	Promotes cooperation among West African nations, including Nigeria, for shared stock management and combating illegal fishing.

Box 1.1: Key international fisheries agreements and their relevance to Nigeria

Pilot questions 1.4

1. State the four fundamental principles of fisheries management.
2. Name five management tools used in fisheries and briefly explain each.
3. State the principal fisheries legislation in Nigeria and name the federal body responsible for enforcement.
4. Explain the importance of UNCLOS to Nigeria's marine fisheries.
5. Explain what IUU fishing is and state one consequence for Nigerian fisheries.



Series Summary

This Series established the foundations of fisheries and aquaculture. We defined fisheries and aquaculture, distinguished between them, and described the scope and branches of fisheries science. We explained the nutritional importance of fish in Nigeria (40 per cent of animal protein, omega-3 fatty acids, minerals, vitamins) and the economic importance (GDP contribution, 8 million jobs, catfish agribusiness). We described the three sub-sectors of the Nigerian fish industry (artisanal, industrial, aquaculture) and the major causes and consequences of the supply-demand gap (2.5 million metric tonnes imported annually).

We surveyed the freshwater resources (Niger-Benue system, Lake Chad, major reservoirs), the marine and coastal resources (Gulf of Guinea, 853 km coastline, 200 nm EEZ), and the most important fish species (*Clarias gariepinus*, *Oreochromis niloticus*, *Ethmalosa fimbriata*, *Lates niloticus*, crayfish). We covered the fundamental principles of fisheries management (precautionary principle, ecosystem-based management, MSY, adaptive management), Nigeria's fisheries legislation (Fisheries Act Cap F10), institutional responsibilities (FDF, NIOMR, NIFFR), and key international agreements (UNCLOS, CCRF, CBD, CECAF, LCBC). By completing this Series, you should be able to achieve all eight Series Learning Outcomes (SLO 1.1 to SLO 1.8).

Glossary of Terms

- **Aquaculture:** the controlled cultivation of aquatic organisms (fish, shellfish, crustaceans, molluscs, aquatic plants) in freshwater, brackish, or marine water, involving deliberate intervention to increase production.
- **Artisanal fisheries:** small-scale, traditional fishing operations using non-mechanised or lightly motorised vessels and traditional gears; the majority of Nigerian fishing employment.
- **By-catch:** non-target organisms unintentionally caught during fishing operations; a major sustainability concern in industrial trawl fisheries.



- **CECAF (Fishery Committee for the Eastern Central Atlantic):** the FAO regional fishery body providing scientific advice for management of shared fish stocks in the Gulf of Guinea.
- **Clarias gariepinus:** the African catfish; the most important farmed fish in Nigeria; hardy, fast-growing, air-breathing, and commands high market prices.
- **Closed season:** a period during which fishing is prohibited to protect fish during spawning aggregations.
- **Demersal fish:** fish that live and feed near the bottom of a water body; examples in Nigeria include croakers, snappers, and groupers.
- **Ethmalosa fimbriata:** the bonga shad; the most important artisanal marine fish species in Nigeria; caught in large quantities and smoked.
- **Exclusive Economic Zone (EEZ):** the 200-nautical-mile zone from the coast within which a coastal state has sovereign rights over living and non-living marine resources under UNCLOS.
- **Federal Department of Fisheries (FDF):** the federal agency under the Ministry of Agriculture responsible for national fisheries policy, stock assessment, and enforcement in Nigeria.
- **Fisheries:** the science and practice concerned with the harvesting, management, and conservation of fish and other aquatic organisms from their natural environments.
- **Fish stock:** a population of fish of one species in a defined area that is managed as a unit.
- **IUU fishing (Illegal, Unreported, Unregulated):** fishing operations that violate national or international fisheries regulations, or are not reported to management authorities; a major threat to Nigerian marine fisheries.
- **Lake Chad Basin Commission (LCBC):** the intergovernmental body coordinating management of Lake Chad resources among Nigeria, Niger, Cameroon, and Chad.
- **Maximum sustainable yield (MSY):** the largest average catch that can be harvested from a stock under prevailing environmental conditions on a sustainable basis; a key fisheries management reference point.
- **NIFFR (National Institute for Freshwater Fisheries Research):** the national research institute for freshwater fisheries science in Nigeria, located at New Bussa, Niger State.



- **NIOMR (Nigerian Institute for Oceanography and Marine Research):** the national research institute for marine and oceanographic sciences in Nigeria, located in Lagos.
- **Oreochromis niloticus:** the Nile tilapia; the second most farmed fish species in Nigeria; omnivorous, fast-growing, and widely accepted in markets.
- **Pelagic fish:** fish that live and feed in open water, often in schools near the surface; examples in Nigeria include bonga, mackerel, and sardinellas.
- **Precautionary principle:** the principle that in the absence of adequate scientific information, fisheries management decisions should err on the side of conservation to avoid irreversible stock depletion.
- **Sustainable yield:** the quantity of fish that can be harvested repeatedly over time without depleting the stock below a level from which it can recover.
- **Total allowable catch (TAC):** the total quantity of fish of a species that may be harvested from a stock in a given period, set as a management measure below MSY to ensure stock sustainability.
- **UNCLOS (United Nations Convention on the Law of the Sea):** the international treaty establishing the legal framework for all activities in the oceans, including the 200-nautical-mile Exclusive Economic Zone.

Concept Check Questions [Series 1]

Objective Questions

1. Aquaculture involves deliberate _____ in the rearing process to increase production above what natural environments would yield. (Linked to SLO 1.1)
2. Fish contributes approximately _____ per cent of total animal protein intake in Nigeria. (Linked to SLO 1.4)
3. The two most important aquaculture species in Nigeria are *Clarias gariepinus* (African catfish) and _____ *niloticus* (Nile tilapia). (Linked to SLO 1.7)
4. The _____ principle states that management decisions should err on the side of conservation in the absence of adequate scientific information. (Linked to SLO 1.8)



5. Nigeria's Exclusive Economic Zone extends _____ nautical miles from the coast under UNCLOS. (Linked to SLO 1.8)

Short-Answer Questions

6. Distinguish between capture fisheries and aquaculture and give two advantages of each. (Linked to SLO 1.3)
7. State the nutritional importance of fish for vulnerable groups in Nigeria. (Linked to SLO 1.4)
8. Describe the three sub-sectors of the Nigerian fish industry. (Linked to SLO 1.5)
9. Name five important fish species of Nigeria and state the habitat and primary use of each. (Linked to SLO 1.7)
10. Name four management tools used in fisheries and explain each briefly. (Linked to SLO 1.8)

Long-Answer Questions

11. Discuss the importance of fisheries and aquaculture to Nigeria, covering nutritional significance, economic contribution, the structure of the fish industry, and the fish supply-demand gap. (Linked to SLOs 1.4, 1.5)
12. Describe the freshwater and marine fisheries resources of Nigeria, identifying major water bodies, important fish families, and economically significant species. (Linked to SLOs 1.6, 1.7)
13. Explain the fundamental principles of fisheries management, describe Nigeria's fisheries legislation and institutions, and evaluate Nigeria's obligations under international fisheries agreements. (Linked to SLO 1.8)

Answers to Concept Check Questions [Series 1]

Objective Questions

1. Intervention.
2. 40.



3. Oreochromis.
4. Precautionary.
5. 200.

Short-Answer Questions

6. Capture fisheries harvest fish from natural habitats using nets, traps, and lines; the stock is wild and the harvest is limited by natural productivity. Advantages: no investment in infrastructure or feed; exploits existing natural resource. Aquaculture grows fish under controlled conditions in ponds, cages, or tanks; the farmer controls feeding, stocking, water quality, and reproduction. Advantages: yields far higher than natural water bodies; can be done close to markets reducing transport cost.
7. For children: high-quality protein for growth; omega-3 fatty acids (DHA and EPA) for brain development. For pregnant and lactating women: omega-3 fatty acids for fetal and infant neural development; iodine for thyroid function. For the elderly: protein for muscle maintenance; vitamin D and calcium from small whole fish for bone health. For all: affordable animal protein, especially dried and smoked fish products accessible to low-income households.
8. Artisanal fisheries: small-scale traditional fishing on rivers, lakes, estuaries, and coastal waters using dugout canoes, wooden boats, and traditional gear; employs the majority of fishers. Industrial fisheries: large trawlers and purse-seiners operating in the EEZ, owned mainly by large companies; targets demersal and pelagic ocean species. Aquaculture: controlled cultivation in ponds, tanks, or cages; primarily catfish and tilapia; ranges from backyard operations to large commercial farms.
9. Any five with habitat and use: *Clarias gariepinus* (African catfish; freshwater ponds and rivers; primary aquaculture species, high market price); *Oreochromis niloticus* (Nile tilapia; freshwater; second aquaculture species, table fish); *Ethmalosa fimbriata* (bonga shad; coastal marine; smoked for domestic trade); *Lates niloticus* (Nile perch; freshwater, Lake Chad and Niger; artisanal capture, large food fish); *Nematopalaemon hastatus* (crayfish; coastal estuaries; dried and traded as flavouring ingredient throughout Nigeria).
10. Catch limits (TAC: limits total harvest to below MSY to prevent overfishing); size limits (minimum legal size protects juveniles before they can reproduce); closed seasons (fishing prohibited during spawning to protect reproducing fish); closed areas (spatial closures protect



nursery areas, spawning grounds, and critical habitats); gear regulations (prohibit destructive gears such as poison, explosives, and fine-mesh nets).

Long-Answer Questions

11. Nutritional: fish provides 40% of animal protein in Nigeria; high-quality protein (essential amino acids), omega-3 fatty acids (DHA, EPA for brain development), vitamins A, D, B12, minerals (iodine, selenium, zinc); critical for children, pregnant women, elderly; small dried/smoked fish affordable for low-income households; fish dominant protein source in riverine communities (50-70% of protein). Economic: fisheries sector contributes 1.5-2% of GDP; employs 8+ million in fishing, aquaculture, processing, and trading; women dominate fish trading; catfish farming is a major agribusiness sub-sector in south-western Nigeria; export of crayfish and smoked fish generates some revenue. Fish industry structure: artisanal (canoes, traditional gear, rivers, lakes, coast; majority of employment); industrial (trawlers, purse-seiners, EEZ, government concessions); aquaculture (catfish, tilapia, ponds to RAS). Supply-demand gap: annual demand ~3.5 million metric tonnes; domestic supply ~1 million metric tonnes; ~2.5 million metric tonnes imported (mostly frozen mackerel and herrings) at ~USD 1.5 billion per year in foreign exchange. Post-harvest losses 20-35%; cold chain inadequate.
12. Freshwater resources: 12.5 million hectares inland water; major rivers: Niger-Benue (largest, drains two-thirds of country), Cross, Osun, Ogun, Hadejia-Jama'are-Komadugu, Sokoto-Rima; Lake Chad (shared with Niger, Cameroon, Chad; reduced from 25,000 km² in 1963 to ~1,500 km² today due to climate change and water abstraction); reservoirs: Kainji, Jebba, Shiroro, Tiga, Goronyo, Bakolori; freshwater fish families: Clariidae (catfish), Cichlidae (tilapia), Cyprinidae (carps), Mormyridae (elephantfish), Osteoglossidae (Heterotis); 200+ species in Niger-Benue. Marine and coastal resources: 853 km Atlantic coastline; 200 nm EEZ; Gulf of Guinea highly productive (seasonal upwelling); ecosystems: mangroves, estuaries, Niger Delta, lagoons; demersal fish (croakers, snappers, groupers; trawl-fished); pelagic fish (bonga, mackerel, sardinellas; purse-seines and artisanal lift nets); crustaceans (shrimps, crabs, crayfish in estuaries). Important species: *Clarias gariepinus* (catfish, aquaculture); *Oreochromis niloticus* (tilapia, aquaculture); *Ethmalosa fimbriata* (bonga, marine artisanal); *Lates niloticus* (Nile perch, freshwater); *Nematopalaemon hastatus* (crayfish, coastal, dried trade); *Heterotis niloticus* (arowana, freshwater floodplain); *Gymnarchus niloticus* (aba aba, smoked); sardinellas (coastal pelagic).



13. Fundamental principles: precautionary principle (err on side of conservation without adequate data); ecosystem-based management (consider whole ecosystem, not just target species); MSY (reference point for sustainable harvest); adaptive management (adjust as new data becomes available). Management tools: TAC (total catch limit); size limits (protect juveniles); closed seasons (protect spawning); closed areas (protect habitats); gear regulations (prohibit destructive methods); licensing (control fishing effort). Nigeria legislation: Fisheries Act Cap F10 (2004, regulates fishing, destructive methods, licensing); Sea Fisheries Act (trawling in EEZ); National Policy on Marine Fisheries and Aquaculture Development (2015, expansion and post-harvest loss reduction). Institutions: FDF (national policy, enforcement), NIOMR (marine research, Lagos), NIFFR (freshwater research, New Bussa), state fisheries departments, FISON. International agreements: UNCLOS (EEZ sovereign rights, 200 nm); CCRF FAO 1995 (responsible fishing guidelines); CBD 1992 (biodiversity conservation); CECAF (Gulf of Guinea shared stocks, scientific advice); LCBC (Lake Chad management, Nigeria-Niger-Cameroon-Chad); IUU fishing by foreign vessels: major threat, deprives Nigeria of marine resources.

Answers to Pilot Questions [Series 1]

Part 1.1: Definitions and Scope

1. Fisheries is the science and practice of harvesting, managing, and conserving fish and other aquatic organisms from natural environments; it covers fish biology, capture technology, and the economics of fishing. Aquaculture is the controlled cultivation of aquatic organisms in fresh, brackish, or marine water involving deliberate intervention to increase production beyond natural yield. They differ in that fisheries harvest from wild stocks in natural habitats without controlling reproduction or feeding, while aquaculture controls all aspects of rearing including stocking, feeding, water quality, and reproduction.
2. Maximum sustainable yield (MSY) is the largest average catch that can be harvested from a fish stock under prevailing environmental conditions on a sustainable basis, without reducing the stock's ability to replenish itself. It is important as a management reference point because it defines the upper limit of harvesting that is ecologically sustainable; setting catches below MSY preserves the stock for future seasons while catches consistently above MSY lead to stock collapse and loss of the fishery.



3. Any four: fish biology (anatomy, physiology, behaviour, life history); fisheries ecology (fish-environment interactions, population dynamics); fisheries stock assessment (quantitative evaluation of stock size, growth, mortality, reproduction for management decisions); fishing technology (gear design, vessel operation); aquaculture (controlled rearing); fish processing and preservation (post-harvest quality); fisheries economics and management (economic analysis, governance).
4. NIOMR (Nigerian Institute for Oceanography and Marine Research) in Lagos; NIFFR (National Institute for Freshwater Fisheries Research) in New Bussa, Niger State.
5. Any three: aquaculture can yield far more fish per unit area than natural water bodies by controlling feeding and stocking; aquaculture can be located close to urban markets, reducing transport costs and post-harvest losses; aquaculture is not subject to weather and seasonal variation in fish availability as capture fisheries are; aquaculture allows the farmer to select fast-growing, disease-resistant species and strains for maximum production.

Part 1.2: Importance in Nigeria

1. For children: high-quality protein supports growth; omega-3 fatty acids (DHA and EPA) are essential for brain and neural development; iodine from fish supports thyroid function and cognitive development. For pregnant and lactating women: omega-3 fatty acids support fetal and infant neural development; protein supports fetal growth; vitamins and minerals support maternal health. For the elderly: protein maintains muscle mass; vitamin D and calcium from whole small fish support bone health.
2. Annual Nigerian fish demand is approximately 3.5 million metric tonnes but domestic supply (capture plus aquaculture) is approximately 1 million metric tonnes; the shortfall of approximately 2.5 million metric tonnes is imported at a cost of approximately USD 1.5 billion per year in foreign exchange. This is a food security concern because: dependence on imported fish exposes consumers to price volatility and supply disruptions; the foreign exchange cost is a drain on national reserves; and the domestic supply gap limits protein accessibility for the poorest populations who cannot afford imported frozen fish.
3. The fisheries sector contributes approximately 1.5 to 2 per cent of Nigeria's GDP and employs over 8 million people directly in fishing, aquaculture, fish processing, and fish trading.
4. Artisanal fisheries: small-scale traditional fishing on rivers, lakes, estuaries, and coastal waters using dugout canoes, wooden boats, gill nets, seine nets, traps, and cast nets; employs the



majority of Nigerian fishers and provides the most widely consumed fresh and smoked fish.

Industrial fisheries: trawlers and purse-seiners licensed by government to operate in the Exclusive Economic Zone of the Atlantic Ocean; targets demersal and pelagic marine species; owned mainly by large companies. Aquaculture: controlled cultivation in ponds, tanks, cages, and raceways; primarily African catfish and Nile tilapia; ranges from backyard family ponds to large commercial operations with modern technology.

5. Post-harvest losses are high because: refrigeration and freezing infrastructure is inadequate across much of Nigeria, especially in rural fishing communities; transport from fishing grounds to markets is slow and unreliable; smoking ovens (traditional clay and drum ovens) are inefficient and may partially preserve rather than fully dry the fish; and water content of improperly processed fish allows microbial spoilage. One measure: provision of improved Chorkor smoking kilns to increase efficiency and throughput, combined with solar drying racks, to reduce moisture content and improve preservation quality.

Part 1.3: Fisheries Resources

1. The five major river systems are: Niger-Benue system (largest, drains approximately two-thirds of the country); Cross River (south-eastern Nigeria); Hadejia-Jama'are-Komadugu-Yobe system (north-eastern Nigeria, Lake Chad basin); Sokoto-Rima system (north-western Nigeria); and the Anambra River (south-eastern Nigeria, Niger Delta tributary). The largest is the Niger-Benue system.
2. Lake Chad's current area is approximately 1,500 km², down from approximately 25,000 km² in 1963. Main causes: climate change (reduced rainfall in the Sahel catchment since the late 1960s, reducing inflows from rivers feeding the lake); increased water abstraction from tributary rivers (particularly the Komadugu-Yobe and other northern Nigerian rivers) for irrigation schemes serving the expanding agricultural area; and increased evaporation under rising temperatures.
3. Demersal fish live and feed near the bottom of a water body; Nigerian examples: croakers (*Pseudotolithus* spp.) and snappers (*Lutjanus* spp.) fished by trawlers on the continental shelf. Pelagic fish live and feed in open water, often schooling near the surface; Nigerian examples: bonga shad (*Ethmalosa fimbriata*) and mackerel (*Scomber japonicus*) fished by purse-seiners and artisanal lift nets along the coast.
4. Two most important: (1) African catfish (*Clarias gariepinus*): freshwater; most farmed species in Nigeria; three characteristics: hardy and tolerant of poor water quality including low dissolved



oxygen (air-breathing); fast-growing (reaches 500-800 g in 4-6 months under good management); commands high market price and is preferred fresh by Nigerian consumers. (2) Nile tilapia (*Oreochromis niloticus*): freshwater; second most farmed; three characteristics: omnivorous (eats plant material, algae, and pelleted feed); fast-growing (reaches 300-500 g in 5-6 months); widely accepted in markets in southern Nigeria.

5. Crayfish in Nigeria refers primarily to small dried shrimps and prawns (particularly *Nematopalaemon hastatus* from the Niger Delta and coastal estuaries). Their economic importance is significant: crayfish is a universally used food flavouring ingredient in Nigerian cuisine, used in soups, stews, and sauces across all regions of the country; it is sun-dried and bagged for trade and can be stored for months without refrigeration; it supports the livelihoods of thousands of artisanal fishers in the Niger Delta, particularly women who harvest, dry, and trade the crayfish; and dried crayfish is exported to the Nigerian diaspora in Europe and North America, generating foreign exchange.

Part 1.4: Principles and Policy Framework

1. The four fundamental principles of fisheries management are: (1) the precautionary principle (in the absence of adequate scientific information, management decisions should err on the side of conservation to avoid irreversible depletion); (2) ecosystem-based management (fisheries are managed within the context of the whole ecosystem, considering effects on non-target species, habitats, and ecological processes, not just the target fish stock); (3) maximum sustainable yield (MSY) as a management reference point (the harvest rate should not exceed the rate at which the stock can replenish itself); (4) adaptive management (management measures are adjusted as new scientific information about stock status becomes available).
2. Any five: total allowable catch (TAC: the total quantity of fish that may be harvested from a stock in a given period, set below MSY to ensure sustainability); minimum legal size (fishers must not retain fish below a defined minimum size, protecting juveniles before they have reproduced); closed seasons (fishing is prohibited during specified periods, typically when the target species is spawning, to protect reproductive aggregations); closed areas (specific spatial zones where fishing is permanently or seasonally prohibited to protect nursery areas, spawning grounds, and critical habitats); gear regulations (specific gears that are destructive, such as poisons, explosives, fine-mesh nets, and electric fishing, are prohibited); licensing systems (the



number of fishing vessels, boats, or gear units is controlled through a licensing scheme to limit total fishing effort).

3. The principal fisheries legislation is the Fisheries Act (Cap F10, Laws of the Federation of Nigeria 2004). The federal body responsible for enforcement is the Federal Department of Fisheries (FDF) under the Federal Ministry of Agriculture and Rural Development.
4. UNCLOS establishes Nigeria's Exclusive Economic Zone (EEZ) extending 200 nautical miles from the Atlantic coast, within which Nigeria has sovereign rights over all living marine resources including fish, shrimps, and crabs. This means Nigeria can: exclude foreign fishing vessels from its EEZ (or license them under negotiated agreements); set catch limits for stocks in the EEZ; regulate fishing methods and vessel types in the zone; and take enforcement action against vessels fishing illegally within the zone. Without UNCLOS, the high seas boundary would begin at the territorial sea (12 nm), leaving Nigeria's vast continental shelf open to uncontrolled foreign fishing.
5. IUU (Illegal, Unreported, Unregulated) fishing refers to fishing operations that violate national or international fisheries regulations (illegal), do not report catches to fisheries authorities (unreported), or occur in areas or for species without applicable regulations (unregulated). One consequence for Nigerian fisheries: foreign IUU fishing vessels targeting demersal and pelagic stocks in Nigeria's EEZ without licenses deplete stocks that Nigerian artisanal fishers and licensed vessels depend on, reducing fish availability, depressing incomes of Nigerian fishers, and denying the government the license fees and taxes that would be paid by legitimate fishing operations.

References and Attributions [Series 1]

Textual References (Books and External Sources)

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Figures, Plates, Tables, and Boxes

- Table 1.1: Capture fisheries vs aquaculture comparison Attribution: AI generated. Suggested OER search string: "capture fisheries vs aquaculture comparison Nigeria table OER".
- Figure 1.1: Nigerian fish industry sub-sectors and value chain Attribution: AI generated. Suggested OER search string: "Nigeria fish industry sub-sectors artisanal industrial aquaculture value chain OER".
- Figure 1.2: Map of Nigeria showing major fisheries resources Attribution: AI generated. Suggested OER search string: "Nigeria fisheries resources map freshwater marine EEZ Niger Benue Lake Chad OER".
- Table 1.2: Important fish species of Nigeria Attribution: AI generated. Suggested OER search string: "important fish species Nigeria aquaculture marine freshwater economic use OER table".
- Box 1.1: Key international fisheries agreements relevant to Nigeria Attribution: AI generated. Suggested OER search string: "international fisheries agreements Nigeria UNCLOS CCRF CBD CECAF OER box".



Course code: AGE 308

Course title: Fish Farming and Management

Course credit load: 2 Units

Series 2: Fish Biology, Classification, and Adaptation

- **Part 2.1: Fish Classification and Taxonomy**
 - Sub Part 2.1.1: The major classes of fish
 - Sub Part 2.1.2: Classification of economically important families in Nigeria
 - Sub Part 2.1.3: Principles of fish taxonomy
- **Part 2.2: External Morphology and Internal Anatomy**
 - Sub Part 2.2.1: External features and body form
 - Sub Part 2.2.2: Fins: types, structure, and functions
 - Sub Part 2.2.3: Internal organ systems
- **Part 2.3: Physiology of Aquatic Life**
 - Sub Part 2.3.1: Respiration and the role of gills
 - Sub Part 2.3.2: Osmoregulation and excretion
 - Sub Part 2.3.3: Sensory systems and behaviour
- **Part 2.4: Life Cycles and Reproduction**
 - Sub Part 2.4.1: Reproductive strategies in fish
 - Sub Part 2.4.2: Life cycle of principal Nigerian species



- Sub Part 2.4.3: Factors affecting growth and condition

Introduction

A fish farmer who does not understand the biology of the fish being farmed is like a farmer who does not understand plant growth. Every practical decision in aquaculture, from stocking density to feeding regime to water quality management and disease prevention, is grounded in an understanding of fish biology. This Series provides the biological foundation for the practical fish farming topics covered in Series 3 and 4, covering how fish are classified, how their bodies are structured and function, how they breathe, regulate water and salt balance, and sense their environment, and how they reproduce and grow.

We begin with fish classification and taxonomy, move through external morphology and internal anatomy, cover the physiology of respiration, osmoregulation, and sensory systems, and conclude with reproductive strategies and life cycles of principal Nigerian species. The biological content of this Series directly underpins feeding practices, stocking density decisions, disease management, and broodstock selection in aquaculture.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 2.1** describe the major classes of fish and explain the taxonomic principles used to classify them (Linked to Part 2.1),
- **SLO 2.2** classify the economically important fish families of Nigeria and give examples of species in each (Linked to Part 2.1),
- **SLO 2.3** describe the external features of fish including body form, scales, lateral line, and colouration (Linked to Part 2.2),



- **SLO 2.4** identify and describe the types, structure, and functions of fish fins (Linked to Part 2.2),
- **SLO 2.5** describe the major internal organ systems of a fish and explain the function of each (Linked to Part 2.2),
- **SLO 2.6** explain how fish breathe using gills and describe air-breathing adaptations in catfish (Linked to Part 2.3),
- **SLO 2.7** explain osmoregulation in freshwater and marine fish and describe the excretory system (Linked to Part 2.3),
- **SLO 2.8** describe the reproductive strategies and life cycles of principal Nigerian fish species and explain the factors affecting fish growth (Linked to Part 2.4).

2.1 Fish Classification and Taxonomy

2.1.1 The major classes of fish

Fish belong to the phylum Chordata and are the most diverse group of vertebrates, with over 35,000 known species. They are divided into three major classes: Agnatha (jawless fish; lampreys and hagfish; no jaws, no paired fins, cartilaginous skeleton; primarily marine and parasitic; not present in Nigerian inland waters but relevant for taxonomy); Chondrichthyes (cartilaginous fish; sharks, rays, and chimaeras; jaws present, cartilaginous skeleton, no swim bladder, skin covered with dermal denticles; primarily marine; some sharks and rays enter Nigerian coastal waters); and Osteichthyes (bony fish; by far the largest class, including all Nigerian freshwater fish and most marine species of economic importance; jaws, bony skeleton, usually a swim bladder for buoyancy, scales of various types).

Within Osteichthyes, two subclasses are recognised: Actinopterygii (ray-finned fish; fins supported by bony rays; includes the vast majority of fish species of commercial importance worldwide including all major Nigerian species); and Sarcopterygii (lobe-finned fish; fins with fleshy lobes supported by bone; includes lungfish and the coelacanth; the West African lungfish *Protopterus annectens* is found in Nigerian floodplains and can breathe air and aestivate during



dry seasons, making it of biological interest). All fish species discussed in this course belong to Actinopterygii.

Fill in the blank: Osteichthyes (bony fish) is the largest class of fish and includes all major Nigerian species; the subclass _____ includes ray-finned fish supported by bony rays, which includes virtually all commercially important species.

2.1.2 Classification of economically important families in Nigeria

The economically important fish families of Nigeria and their key characteristics are: Clariidae (catfishes; *Clarias gariepinus*, *Clarias angustifrons*, *Heterobranchus longifilis*; scaleless, elongated body, four pairs of barbels, dorsal fin very long, accessory air-breathing organ present; the most important aquaculture family in Nigeria); Cichlidae (cichlids; *Oreochromis niloticus*, *Tilapia zillii*, *Hemichromis* spp.; spiny dorsal fin, single nostril on each side, interrupted lateral line; second most important aquaculture family); Characidae (tetras and tigerfish; *Hydrocynus vittatus*; small-medium sized, adipose fin present, maxillary teeth; important in artisanal fisheries of the Niger-Benue).

Additional important families: Mormyridae (elephantfish; *Mormyrus rume*, *Gnathonemus petersii*; elongated snout used to probe substrate, weakly electric; artisanal fishery species); Osteoglossidae (arowannas; *Heterotis niloticus*; large scales, long dorsal and anal fins, inferior mouth; floodplain artisanal species); Schilbeidae (*Schilbe* spp.; small catfish with forked tail and short dorsal spine; smoked for trade); Cyprinidae (carps and barbs; *Labeo* spp., *Barbus* spp.; toothless jaws, pharyngeal teeth, cycloid scales; important in both artisanal fisheries and globally in aquaculture but limited Nigerian aquaculture use). Clupeidae (herrings and bonga; *Ethmalosa fimbriata*; strongly keeled belly with scutes, deeply forked tail; the most important coastal artisanal fish in Nigeria).

Fill in the blank: Clariidae (catfish family) is the most important aquaculture family in Nigeria; its members are characterised by a scaleless body, four pairs of _____, a very long dorsal fin, and an accessory air-breathing organ.



<u>Fish Family</u>	<u>Characteristics</u>	<u>Species Examples</u>	<u>Primary Economic Use</u>
Clariidae (Air-breathing catfishes)	Elongated body, accessory breathing organs, hardy in low oxygen waters	<i>Clarias gariepinus</i> , <i>Heterobranchus bidorsalis</i>	Aquaculture, commercial food fish
Cichlidae (Tilapias)	Laterally compressed body, prolific breeders, adaptable to varied habitats	<i>Oreochromis niloticus</i> , <i>Tilapia zillii</i>	Aquaculture, artisanal fisheries
Mugilidae (Mulletts)	Cylindrical body, detritus feeders, coastal and estuarine habitats	<i>Mugil cephalus</i>	Coastal fisheries, smoked/dried fish
Ethmalosidae (Shads)	Schooling pelagic fish, silvery body, estuarine and coastal waters	<i>Ethmalosa fimbriata</i> (Bonga shad)	Artisanal fisheries, smoked fish trade
Serranidae (Perches)	Large predatory fish, firm flesh, found in rivers and lakes	<i>Lates niloticus</i> (Nile perch)	Commercial fisheries, export potential
Sciaenidae (Croakers)	Marine demersal fish, produce drumming sounds, important in coastal waters	<i>Pseudotolithus elongatus</i>	Coastal fisheries, fresh and smoked fish markets
Sardinellidae (Sardines)	Small schooling pelagic fish, abundant in marine waters	<i>Sardinella maderensis</i>	Coastal fisheries, canned fish industry

Table 2.1: Economically important fish families of Nigeria with their characteristics and examples

2.1.3 Principles of fish taxonomy

Taxonomy is the science of classifying and naming organisms. Fish are classified using the Linnaean hierarchical system: Kingdom (Animalia), Phylum (Chordata), Class (e.g. Osteichthyes), Order (e.g. Siluriformes), Family (e.g. Clariidae), Genus (e.g. Clarias), Species



(e.g. gariepinus). The binomial nomenclature system uses the genus and species names to give each organism a unique two-part scientific name (written in italics with the genus capitalised: *Clarias gariepinus*). Scientific names are important because common names vary by language and region: *Clarias gariepinus* is called catfish in English, eja aro or obokun in Yoruba, aro or aro-aro in Igbo, and tarwada in Hausa.

Characters used in fish taxonomy include: morphometric measurements (body length, depth, head length, eye diameter, fin ray counts, scale counts); meristic counts (number of fin rays, scales in lateral line, vertebrae, gill rakers); colour patterns and markings; skeletal characters; and increasingly molecular characters (DNA sequence comparisons). Distinguishing species within the same genus (for example, *Clarias gariepinus* from *Clarias angustifrons*) requires careful examination of these characters. Fish taxonomy is important for aquaculture because different species within the same family may differ significantly in growth rate, disease resistance, and feed conversion, making species identification essential for management.

Fill in the blank: The binomial nomenclature system gives each fish species a unique two-part scientific name composed of the _____ (capitalised) and species (lowercase) names, both written in italics.

Pilot questions 2.1

1. Name the three major classes of fish and state the key difference between Chondrichthyes and Osteichthyes.
2. Explain what Actinopterygii means and why all commercially important Nigerian fish belong to this subclass.
3. Describe the key characteristics of the Clariidae family and give two species examples.
4. Write the full taxonomic classification of *Clarias gariepinus* from Kingdom to Species.
5. Explain why scientific names are more useful than common names in fisheries science.



2.2 External Morphology and Internal Anatomy

2.2.1 External features and body form

The external features of fish reveal much about their ecology, feeding behaviour, and habitat.

Body form (body shape) is classified as: fusiform (streamlined, torpedo-shaped; fast swimmers like mackerel and Nile perch); compressed (flattened from side to side; manoeuvrable in still or slow water, like tilapia and cichlids); depressed (flattened from top to bottom; bottom-dwelling species like flatfish and some catfish); elongated (eel-like; species that live in dense vegetation or burrows like knifefish *Gymnarchus niloticus*); and globiform (round body, little swimming; rare in Nigerian species). Body form is adaptive: fusiform fish live in fast-flowing waters while compressed forms exploit complex environments.

Scales are protective structures covering the body in most bony fish. The main types are: cycloid (smooth-edged, concentric rings; found in soft-rayed fish like carp and tilapia); ctenoid (with small spines on the posterior edge; found in spiny-rayed fish like sea breams and groupers; feel rough to the touch); ganoid (rhomboid, interlocking, enamel-covered; found in primitive fish like *Polypterus bichir*); and placoid (dermal denticles; found in sharks and rays). Catfish (Clariidae) are scaleless (naked skin). The lateral line is a sensory organ running along the side of the body that detects vibrations and pressure changes in the water; it is visible as a row of pores along the flank.

Fill in the blank: The _____ line is a sensory organ visible as a row of pores along the flank of a fish that detects vibrations and pressure changes in the surrounding water.

2.2.2 Fins: types, structure, and functions

Fins are the primary locomotory and stabilising structures of fish. They are classified as median (unpaired, along the body axis) and paired. Median fins: the dorsal fin (on top of the body, provides stability against rolling; may be single, double, or very long as in *Clarias*; may carry sharp spines for defence); the anal fin (beneath the body behind the vent; provides stability and steering); and the caudal fin (tail fin, the primary source of thrust for forward movement; shape



reflects swimming style: forked in fast open-water swimmers, rounded in slow manoeuvrable fish, heterocercal in sharks where the upper lobe is larger).

Paired fins: the pectoral fins (behind the gill cover, one on each side; used for braking, turning, hovering, and steering; in bottom-dwelling fish used for walking on the substrate) and the pelvic fins (beneath the body; used for steering and stability; absent in some species). Some fish have an adipose fin (a small, fleshy, rayless fin between the dorsal and caudal fins; present in catfish, characins, and salmonids; function unclear). The number of fin rays (hard spiny rays vs soft articulated rays) is an important taxonomic character. In *Clarias*, the very long soft dorsal fin and the lack of an adipose fin distinguish it from *Heterobranchius*, which has both a shorter dorsal fin and an adipose fin.

Fill in the blank: The _____ fin is the tail fin and the primary source of thrust; in fast open-water swimmers it is forked, while in slow, manoeuvrable fish it tends to be rounded.



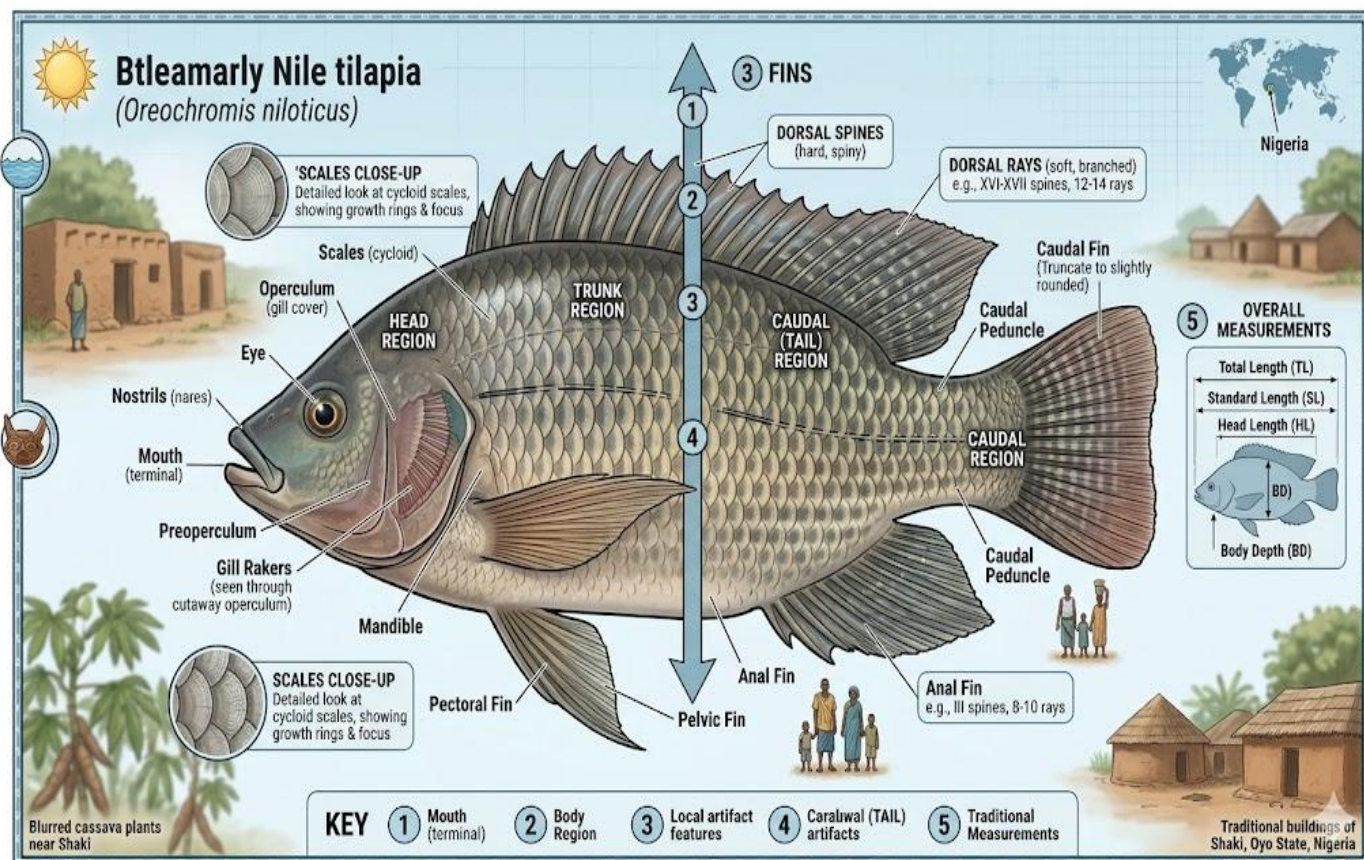


Figure 2.1: Labelled diagram of the external morphology of a tilapia showing body regions and fin types

2.2.3 Internal organ systems

The major internal organ systems of fish are: the digestive system (mouth, oesophagus, stomach, pyloric caeca in some species, intestine, liver, gallbladder, pancreas; length of intestine is related to diet: herbivores and omnivores have longer intestines than carnivores; catfish have a simple stomach and long intestine); the circulatory system (two-chambered heart with one atrium and one ventricle; single circulation through gills; blood pumped from heart to gills for oxygenation, then to body tissues, then back to heart; gills are the site of oxygen uptake and carbon dioxide release); and the respiratory system (gills on each side, covered by the operculum; four gill arches on each side, each bearing two rows of gill filaments with lamellae where gas exchange occurs; catfish also possess accessory breathing organs for air-breathing).



Additional systems: the swim bladder (a gas-filled sac in the dorsal body cavity that provides neutral buoyancy without energy expenditure; absent in some bottom-dwelling species and in all Clariidae catfish; in some primitive fish it connects to the gut and functions as an accessory lung); the reproductive system (testes in males, ovaries in females; most fish are oviparous, releasing eggs and sperm into water; some species show parental care); the nervous system (brain with well-developed optic lobes for vision, olfactory bulbs for smell; spinal cord along the vertebral column; lateral line nerve for mechanosensory input); and the urinary system (kidneys anterior and posterior; excrete mostly ammonia in freshwater fish).

Fill in the blank: The swim bladder is a gas-filled sac that provides neutral _____ without energy expenditure; it is absent in Clariidae catfish, which must swim actively to maintain position.

Pilot questions 2.2

1. Name and describe four body forms found in fish and give one Nigerian example of each.
2. Distinguish between cycloid and ctenoid scales and give one example of a fish family with each type.
3. Name the five types of fins in a bony fish and state the function of each.
4. Describe the digestive system of a catfish and explain how intestine length relates to diet.
5. Explain the function of the swim bladder and state why it is absent in Clariidae.

2.3 Physiology of Aquatic Life

2.3.1 Respiration and the role of gills

Fish obtain oxygen dissolved in water by passing water over the gill filaments, where a countercurrent exchange system maximises oxygen uptake. Water enters through the mouth, passes over the gill arches inside the opercular cavity, and exits through the opercular opening. The gill lamellae have very thin walls (one or two cells thick), are densely supplied with blood capillaries, and are oriented so that water flows in the opposite direction to blood flow



(countercurrent exchange), ensuring that blood leaving the gills is almost fully saturated with oxygen even from water with relatively low oxygen content. Each gill arch also bears gill rakers, comb-like projections that prevent food particles from passing over the gills and damaging the filaments.

African catfish (*Clarias gariepinus*) and related clariids have an accessory breathing organ, a tree-like structure of branching air-breathing chambers (arborescences) located above the gills in the suprabranchial chamber. The fish rises to the water surface and gulps air; oxygen from the air diffuses across the thin-walled arborescences into the bloodstream. This adaptation allows *Clarias* to survive in severely oxygen-depleted water (such as stagnant ponds, poorly aerated tanks, and water-logged soil), migrate overland during rains (using both gills and the air-breathing organ), and tolerate higher stocking densities in aquaculture than purely gill-breathing species. Water temperature strongly affects dissolved oxygen: warm water holds less oxygen than cool water, making aeration more critical in hot Nigerian conditions.

Fill in the blank: The countercurrent exchange system in gills maximises oxygen uptake by ensuring that water and blood flow in _____ directions across the gill lamellae, so blood is almost fully saturated even from low-oxygen water.

2.3.2 Osmoregulation and excretion

Osmoregulation is the process by which fish maintain the salt and water balance of their body fluids against the osmotic gradient between their internal environment and the surrounding water. Freshwater fish (including all Nigerian aquaculture species) live in water that is more dilute than their body fluids; water therefore continuously enters by osmosis through the gills and skin, and ions are continuously lost. To compensate, freshwater fish produce large quantities of very dilute urine (up to one-third of their body weight per day in some species) to expel excess water, and actively absorb ions (sodium, chloride, calcium) from the water through specialised cells (ionocytes or chloride cells) on the gill filaments.

Marine fish face the opposite problem: seawater is more concentrated than their body fluids, so water is continuously lost and ions gained. Marine teleosts drink seawater continuously, absorb water in the gut, and actively excrete excess sodium and chloride through the gills; they produce



very small quantities of concentrated urine. Euryhaline species (those that can tolerate a wide range of salinities), such as Nile tilapia and some mullets, have highly flexible osmoregulatory systems, making them candidates for culture in brackish water environments. The primary nitrogenous waste product in freshwater fish is ammonia (ammoniotelic excretion), excreted mainly across the gills rather than in urine; ammonia accumulation in poorly managed ponds is a major cause of fish mortality.

Fill in the blank: The primary nitrogenous waste product in freshwater fish is _____, excreted mainly across the gills; its accumulation in poorly managed fish ponds is a major cause of fish mortality.

2.3.3 Sensory systems and behaviour

Fish possess highly developed sensory systems adapted to the aquatic environment. Vision: the fish eye is structurally similar to the vertebrate eye but adapted for focusing in water; most fish have wide-angle monocular vision, with some binocular overlap in front; colour vision is well-developed in diurnal species (tilapia, cichlids). Chemoreception: fish have an excellent sense of smell (olfaction) through paired nostrils that open and close without connecting to the pharynx; taste buds occur on the lips, barbels, and body surface as well as in the mouth; catfish use their barbels extensively for chemosensory exploration of the substrate in low-visibility conditions.

The lateral line system detects low-frequency vibrations, pressure changes, and water currents through mechanoreceptors (neuromasts) distributed along the lateral line canal and on the head. It allows fish to detect prey, predators, obstacles, and other fish in low-visibility or complete darkness. Mormyridae (elephantfish) and *Gymnarchus niloticus* produce weak electric fields and detect distortions in the field caused by nearby objects or other fish, using their electrosensory lateral line for navigation and communication in turbid, low-visibility Nigerian rivers. These sensory adaptations have practical implications for pond management: disturbances around the pond (noise, vibration, shadows) stress fish; catfish locate pelleted feed by smell and touch of barbels, making feed sinking rate and placement important management variables.



Fill in the blank: The _____ line system detects low-frequency vibrations and pressure changes through mechanoreceptors distributed along the body, enabling fish to detect prey, predators, and obstacles in low visibility or darkness.

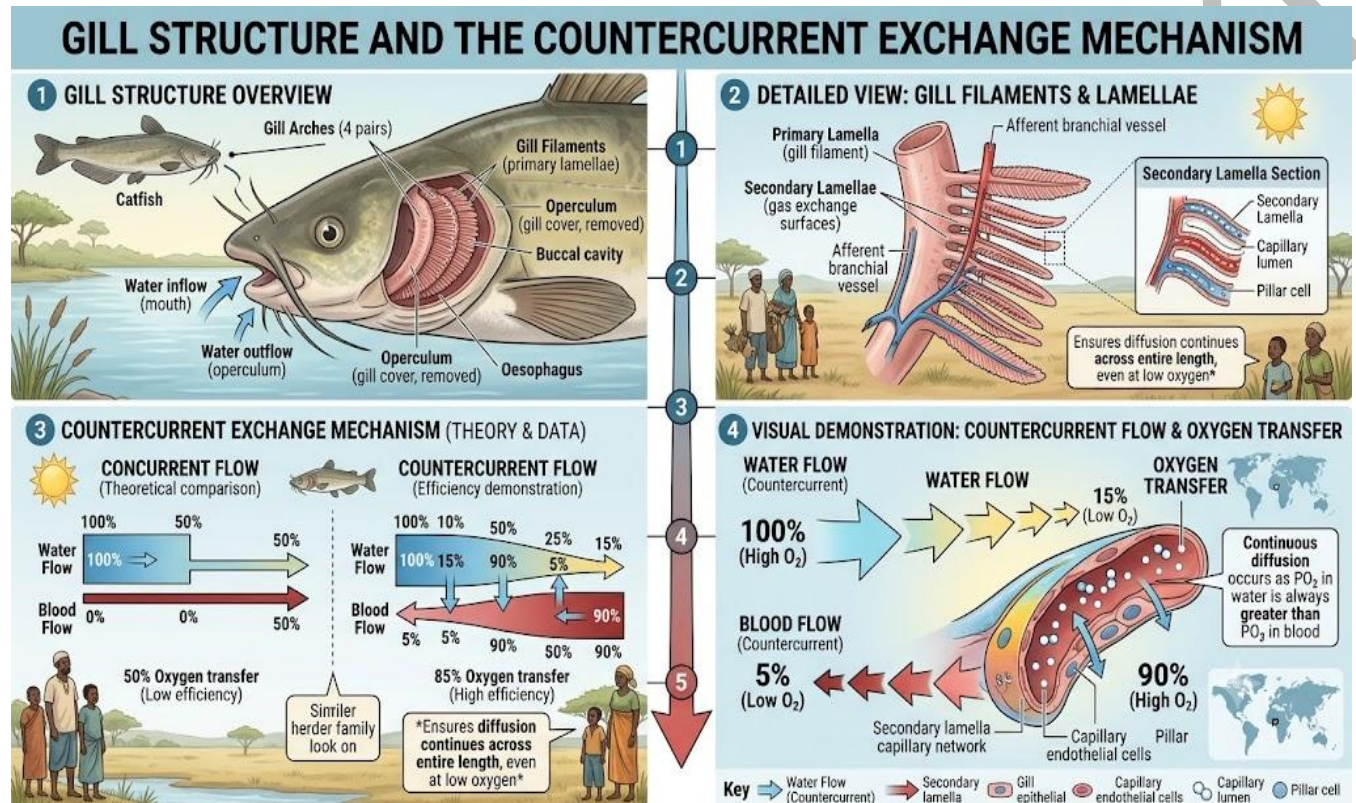


Figure 2.2: Diagram of the gill structure and countercurrent exchange mechanism in a bony fish

Pilot questions 2.3

1. Explain how the countercurrent exchange system in fish gills maximises oxygen uptake.
2. Describe the accessory air-breathing organ of *Clarias gariepinus* and explain its aquaculture significance.
3. Explain how freshwater fish regulate water and salt balance (osmoregulation).
4. Explain what ammonia toxicity is and how it arises in fish ponds.
5. Describe the chemosensory systems of catfish and explain how they affect feeding management in aquaculture.



2.4 Life Cycles and Reproduction

2.4.1 Reproductive strategies in fish

Most fish are gonochoristic (separate sexes) and oviparous (egg-laying). Eggs are fertilised externally in the water column (broadcast spawning) or near a nest. Reproductive strategies vary widely: broadcast spawners (pelagic spawners releasing millions of tiny eggs into open water with no parental care; high mortality, high fecundity; common in marine species such as bonga and mackerel); substrate spawners (eggs attached to plants, rocks, or nest material; fewer eggs but with some parental care; tilapia, jewel fish); and mouthbrooders (female or male incubates eggs and larvae in the mouth; very few eggs but high survival; Nile tilapia *Oreochromis niloticus* is a mouthbrooder, the female incubating eggs for 10 to 15 days, which reduces total fecundity but greatly increases survival of young).

A small number of fish species are ovoviviparous (eggs retained inside the mother and hatched internally before release; some sharks and guppies) or viviparous (live birth with placental-like connection; rare in fish). Sexual maturation age varies from a few months in small species to several years in large species: *Clarias gariepinus* matures at approximately 6 to 12 months and 150 to 200 g body weight; *Oreochromis niloticus* at approximately 4 to 6 months; *Lates niloticus* at 3 to 4 years. Early maturation is a challenge in tilapia aquaculture because the fish diverts energy from growth to reproduction, reducing market-weight attainment. Monosex (all-male) culture of tilapia avoids this problem.

Fill in the blank: Nile tilapia (*Oreochromis niloticus*) is a _____ in which the female incubates eggs in her mouth for 10 to 15 days, reducing total fecundity but greatly increasing survival of the young.

2.4.2 Life cycle of principal Nigerian species

Clarias gariepinus (African catfish): spawning is induced by rising water levels and temperature at the onset of rains (March to May in southern Nigeria; May to June in the north); in aquaculture, hormonal induction (injection of carp pituitary extract or synthetic hormones such as Ovaprim) is used to synchronise spawning; female releases 10,000 to 50,000 eggs per



spawning; eggs hatch in 18 to 24 hours at 27 to 30 degrees Celsius; larvae become free-swimming yolk-sac fry in 3 to 5 days and are reared in hatchery tanks on *Artemia nauplii* and finely ground feed; fingerlings (2 to 5 g) are stocked into nursery ponds; grow-out to market weight (500 g to 1 kg) takes 4 to 6 months.

Oreochromis niloticus (Nile tilapia): spawns throughout the year in Nigerian conditions but peaks in warm seasons; female collects fertilised eggs into the mouth immediately after laying; larvae are released from the mouth after 10 to 14 days as free-swimming fry approximately 8 to 12 mm in length; early maturation (from 4 months) causes overcrowding in ponds unless monosex culture or predator control is practised; in hatcheries, monosex male fry are produced by oral administration of 17-alpha-methyltestosterone in feed during the first 28 to 30 days post-hatching (sex reversal). Market weight (300 to 500 g) is reached in 5 to 7 months under good management. *Lates niloticus* (Nile perch) has a more complex life cycle with offshore spawning, pelagic larvae, and a shift to piscivory as juveniles.

Fill in the blank: Hormonal induction of spawning in *Clarias gariepinus* uses injection of carp pituitary extract or synthetic hormones such as _____ to synchronise egg release in broodstock held in hatchery conditions.

2.4.3 Factors affecting growth and condition

Fish growth is indeterminate (continues throughout life, though slowing with age) and is strongly influenced by environmental and biological factors. Temperature is the most important environmental factor: African catfish grow optimally at 25 to 30 degrees Celsius; below 20 degrees growth slows markedly and below 15 degrees feeding ceases. Dissolved oxygen must remain above 4 mg/L for normal growth; below 2 mg/L catfish switch to air-breathing, growth slows, and mortality risk rises. Feed availability and quality directly determine growth rate: fish fed a well-formulated diet with 35 to 45 per cent crude protein achieve the target feed conversion ratio (FCR) of 1.2 to 1.8 kg feed per kg fish produced.

Biological factors affecting growth include: genetics (fast-growing strains of *Clarias* and *Oreochromis* have been selected and can outperform local strains by 20 to 40 per cent); sex (male tilapia grow faster than females due to the energy cost of mouthbrooding, justifying



monosex male culture); age and size (growth rate is highest in juveniles and declines with increasing size and age); stocking density (high stocking densities increase competition for feed and space, increase stress and disease susceptibility, and reduce individual growth rates); and disease status (parasites, bacteria, and viruses redirect energy from growth to immunity and tissue repair). Condition factor $K = (100 \times W) / L^3$, where W is weight in grams and L is length in centimetres, measures how well-fed and healthy an individual fish is relative to its length.

Fill in the blank: The condition factor $K = (100 \times W) / L^3$ measures how _____ a fish is relative to its length; a high K value indicates a well-fed, healthy individual.

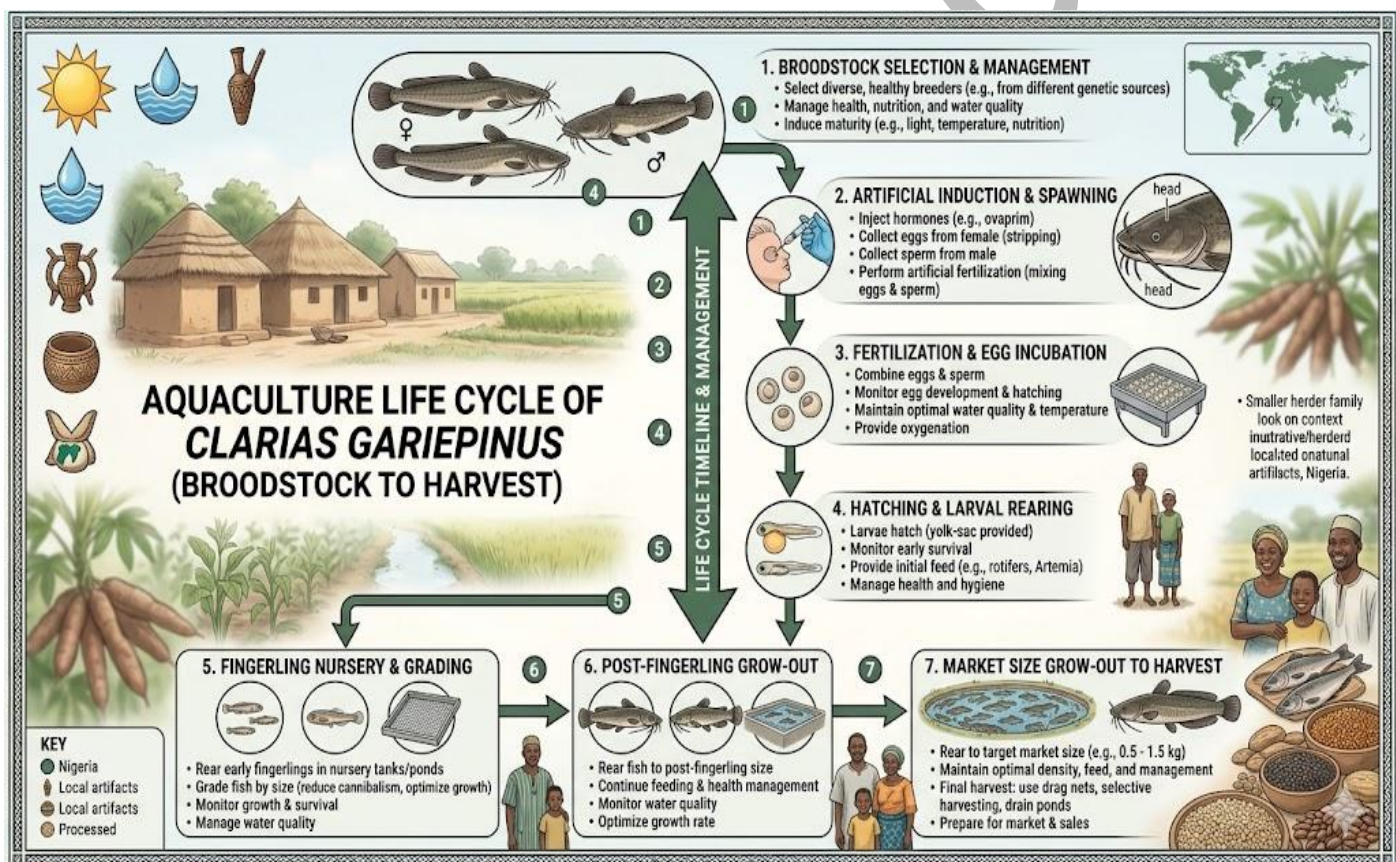


Figure 2.3: Diagram of the life cycle of *Clarias gariepinus* in aquaculture from broodstock to market



Pilot questions 2.4

1. Distinguish between oviparous, ovoviviparous, and mouthbrooding reproductive strategies and give one Nigerian example of each type.
2. Describe the spawning behaviour of *Clarias gariepinus* in nature and explain how it is replicated in hatchery conditions.
3. Explain the problem of early sexual maturation in tilapia aquaculture and describe two methods of controlling it.
4. State five environmental and biological factors that affect the growth of fish in aquaculture ponds.
5. Define the condition factor K, write its formula, and explain how it is used in fish pond management.

Series Summary

This Series covered the biology of fish relevant to aquaculture and fisheries management. We classified fish into three major classes (Agnatha, Chondrichthyes, Osteichthyes), described the subclass Actinopterygii (ray-finned bony fish) to which all commercially important Nigerian species belong, and classified the major economically important families (Clariidae, Cichlidae, Clupeidae, Mormyridae, Osteoglossidae, Characidae, Cyprinidae). We described external morphology (body forms: fusiform, compressed, depressed, elongated; scale types; lateral line) and internal anatomy (digestive, circulatory, respiratory, swim bladder, reproductive, nervous, urinary systems).

We covered fish physiology: gill respiration and the countercurrent exchange mechanism, the accessory air-breathing organ of *Clarias* and its aquaculture significance, osmoregulation in freshwater fish (excess water removed, ions actively absorbed), ammonia as the primary nitrogenous waste, and the sensory systems (vision, chemoreception via nostrils and barbels, lateral line mechanoreception, electroreception in mormyrids). Finally, we described



reproductive strategies (broadcast spawning, substrate spawning, mouthbrooding in *Oreochromis*), the aquaculture life cycles of *Clarias gariepinus* and *Oreochromis niloticus*, and the factors affecting fish growth (temperature, dissolved oxygen, feed, genetics, sex, stocking density, disease) including the condition factor formula. By completing this Series, you should be able to achieve all eight Series Learning Outcomes (SLO 2.1 to SLO 2.8).

Glossary of Terms

- **Accessory breathing organ:** a specialised vascularised structure above the gills in clariid catfish that absorbs atmospheric oxygen; allows survival in oxygen-depleted water.
- **Adipose fin:** a small, fleshy, rayless fin between the dorsal and caudal fins; present in catfish, characins, and salmonids.
- **Actinopterygii:** the subclass of ray-finned bony fish in which the fins are supported by bony rays; includes virtually all commercially important fish species.
- **Ammonia toxicity:** the harmful accumulation of ammonia (the primary nitrogenous waste of freshwater fish) in poorly managed fish ponds; a major cause of fish mortality in intensive aquaculture.
- **Binomial nomenclature:** the Linnaean system of giving each organism a unique two-part scientific name consisting of genus (capitalised) and species (lowercase), written in italics.
- **Broadcast spawning:** a reproductive strategy in which eggs and sperm are released into open water simultaneously; produces millions of eggs but with no parental care.
- **Caudal fin:** the tail fin; the primary source of thrust for forward locomotion in most fish.
- **Chondrichthyes:** the class of cartilaginous fish including sharks, rays, and chimaeras; jaws present, no bony skeleton, no swim bladder.
- **Chloride cells (ionocytes):** specialised cells on gill filaments that actively transport ions from the water into the body; essential for osmoregulation in freshwater fish.



- **Cichlidae:** the cichlid family; includes *Oreochromis niloticus* (Nile tilapia), the second most important aquaculture fish in Nigeria.
- **Clariidae:** the clariid catfish family; includes *Clarias gariepinus* and *Heterobranchus* spp.; scaleless, air-breathing, four pairs of barbels; the most important aquaculture family in Nigeria.
- **Condition factor (K):** $K = (100 \times W) / L^3$; a measure of the plumpness and health of a fish relative to its length; higher values indicate better nutritional condition.
- **Countercurrent exchange:** the physiological mechanism in fish gills in which water and blood flow in opposite directions, maximising the efficiency of oxygen uptake.
- **Ctenoid scales:** fish scales with small spines (ctenii) on the posterior edge; feel rough to the touch; found in spiny-rayed fish such as cichlids and sea breams.
- **Cycloid scales:** smooth-edged fish scales with concentric growth rings; found in soft-rayed fish such as carp.
- **Euryhaline:** the ability of a fish to tolerate a wide range of salinities; examples: Nile tilapia, grey mullet.
- **Feed conversion ratio (FCR):** the amount of feed (kg) required to produce 1 kg of fish body weight; lower is better; well-managed catfish achieve FCR of 1.2 to 1.8.
- **Fecundity:** the number of eggs produced by a female fish in a single spawning or per unit time.
- **Gill rakers:** comb-like projections on the inside of gill arches that prevent food particles from damaging the gill filaments.
- **Lateral line:** a sensory organ running along the side of the body that detects low-frequency vibrations and pressure changes in the water through mechanoreceptors (neuromasts).
- **Mouthbrooder:** a fish that incubates eggs and larvae inside the buccal cavity (mouth) of one parent; reduces fecundity but greatly increases larval survival.



- **Operculum:** the bony gill cover that protects the gills and, by opening and closing, assists in water flow over the gill filaments.
- **Osmoregulation:** the physiological process by which fish maintain the salt and water balance of their body fluids against the osmotic gradient of the surrounding water.
- **Ovaprim:** a synthetic hormone preparation (salmon GnRH analogue + domperidone) used for hormonal induction of spawning in *Clarias gariepinus* and other aquaculture species.
- **Oviparous:** a reproductive strategy in which eggs are laid and fertilised externally; the most common strategy in bony fish.
- **Swim bladder:** a gas-filled sac in the dorsal body cavity of most bony fish that provides neutral buoyancy; absent in Clariidae and bottom-dwelling species.

Concept Check Questions [Series 2]

Objective Questions

1. All commercially important Nigerian fish belong to the subclass _____ (ray-finned fish) within Osteichthyes. (Linked to SLO 2.1)
2. Clariidae (catfish family) are characterised by a scaleless body, four pairs of barbels, a very long dorsal fin, and an accessory _____ organ. (Linked to SLO 2.2)
3. The _____ line is a sensory organ along the fish flank that detects vibrations and pressure changes in the water. (Linked to SLO 2.3)
4. In fish gills, water and blood flow in _____ directions (countercurrent exchange), maximising oxygen uptake efficiency. (Linked to SLO 2.6)
5. Nile tilapia (*Oreochromis niloticus*) is a _____, incubating eggs in the female's mouth for 10 to 15 days. (Linked to SLO 2.8)



Short-Answer Questions

6. Write the full taxonomic classification of *Clarias gariepinus* from Kingdom to Species. (Linked to SLO 2.1)
7. Name four body forms in fish, give the ecological habitat associated with each, and give one Nigerian example. (Linked to SLO 2.3)
8. Explain how freshwater fish regulate water and salt balance. (Linked to SLO 2.7)
9. Describe the aquaculture life cycle of *Clarias gariepinus* from spawning to market weight. (Linked to SLO 2.8)
10. Define the condition factor K, write its formula, and explain when it would be applied in a fish farm. (Linked to SLO 2.8)

Long-Answer Questions

11. Describe the classification and taxonomy of fish, covering the three major classes, the important families of Nigerian aquaculture and capture fisheries, and the principles of fish taxonomy and nomenclature. (Linked to SLOs 2.1, 2.2)
12. Describe the external morphology and internal anatomy of a bony fish, including body form, scale types, fin types and functions, and the major internal organ systems. (Linked to SLOs 2.3, 2.4, 2.5)
13. Describe the physiology of respiration, osmoregulation, and sensory systems in fish, and explain the reproductive strategies and life cycles of *Clarias gariepinus* and *Oreochromis niloticus*, including the factors affecting growth. (Linked to SLOs 2.6, 2.7, 2.8)

Answers to Concept Check Questions [Series 2]

Objective Questions

1. Actinopterygii.
2. Air-breathing.



3. Lateral.
4. Opposite.
5. Mouthbrooder.

Short-Answer Questions

6. Kingdom: Animalia; Phylum: Chordata; Class: Osteichthyes; Order: Siluriformes; Family: Clariidae; Genus: Clarias; Species: gariepinus. Full name: Clarias gariepinus.
7. Fusiform (streamlined, fast-flowing water; mackerel, Nile perch); compressed (flattened side to side, slow/still water complex habitats; tilapia, cichlids); depressed (flattened top to bottom, bottom-dwelling; flatfish, some catfish); elongated (eel-like, vegetation or burrows; *Gymnarchus niloticus*, knifefish).
8. Freshwater fish live in water more dilute than their body fluids; water enters by osmosis through gills and skin; ions are continuously lost. To compensate: the kidneys produce large quantities of very dilute urine to expel excess water; and ionocytes (chloride cells) on the gill filaments actively absorb sodium, chloride, and calcium ions from the water to replace those lost.
9. Hormonal induction with carp pituitary extract or Ovaprim; female releases 10,000-50,000 eggs; fertilisation in water; eggs hatch in 18-24 hours at 27-30 degrees Celsius; yolk-sac larvae for 3-5 days; exogenous feeding on *Artemia* and fry feed; fingerlings (2-5 g) by 3-4 weeks; stocked into nursery then grow-out ponds; market weight (500 g to 1 kg) reached in 4-6 months.
10. Condition factor $K = (100 \times W) / L^3$, where W = weight in grams and L = length in centimetres. It is used in pond management to assess the nutritional status and health of sampled fish: if K values are declining despite adequate feeding, the farmer investigates causes (disease, poor feed quality, overcrowding, water quality problems); if K values are high and uniform, the pond is being managed well.

Long-Answer Questions



11. Three major classes: Agnatha (jawless: lampreys, hagfish; no jaws, cartilaginous, not in Nigerian inland waters); Chondrichthyes (cartilaginous: sharks, rays; jaws, no bony skeleton, no swim bladder, placoid scales; coastal marine in Nigeria); Osteichthyes (bony fish: jaws, bony skeleton, usually swim bladder; all major Nigerian species). Subclass Actinopterygii (ray-finned) contains all commercial Nigerian species. Important families: Clariidae (catfish; scaleless, four barbel pairs, long dorsal fin, air-breathing; *Clarias gariepinus*, *Heterobranchus* spp.); Cichlidae (cichlids; spiny dorsal, single nostril, interrupted lateral line; *Oreochromis niloticus*, *Tilapia zillii*); Clupeidae (bonga; keeled belly scutes, forked tail; *Ethmalosa fimbriata*); Mormyridae (elephantfish; elongated snout, weakly electric; artisanal); Osteoglossidae (arowannas; large scales, long dorsal/anal; *Heterotis niloticus*); Characidae (tetras, tigerfish; adipose fin, maxillary teeth; *Hydrocynus vittatus*); Cyprinidae (carps; no jaw teeth, pharyngeal teeth; Labeo, Barbus). Taxonomy: Linnaean hierarchy (Kingdom to Species); binomial nomenclature (Genus species in italics); taxonomic characters (morphometric measurements, meristic counts, colour, molecular DNA).
12. Body forms: fusiform (fast swimmers, open water; mackerel, Nile perch); compressed (manoeuvrable, still water; tilapia); depressed (bottom-dwellers; flatfish); elongated (vegetation/burrows; *Gymnarchus*). Scale types: cycloid (smooth, concentric rings; soft-rayed fish like carp); ctenoid (spiny posterior edge, rough; spiny-rayed like cichlids); ganoid (rhomboid, enamel-covered; *Polypterus*); placoid (dermal denticles; sharks); scaleless (Clariidae). Lateral line: row of pores along the flank; detects vibrations and pressure. Fins: dorsal (stability, defence; long in Clarias; spiny in tilapia); anal (stability, steering); caudal (thrust; forked in fast swimmers); pectoral (braking, turning, steering); pelvic (stability, steering); adipose (Clariidae lack it; *Heterobranchus* has it). Internal systems: digestive (mouth, oesophagus, stomach, intestine, liver, gallbladder; long intestine in omnivores/herbivores; shorter in carnivores); circulatory (two-chambered heart, single circulation through gills); respiratory (four gill arches, lamellae, countercurrent exchange; accessory organ in Clariidae); swim bladder (buoyancy; absent in Clariidae); reproductive (testes/ovaries); nervous (brain with optic and olfactory lobes, lateral line nerve); urinary (kidneys, ammonia excretion).



13. Respiration: water enters mouth, passes over gill arches, exits through opercular opening; countercurrent exchange (water and blood in opposite directions) in lamellae maximises O₂ uptake; gill rakers protect filaments. Clarias accessory organ: tree-like arborescences above gills in suprabranchial chamber; absorbs atmospheric O₂; allows survival in oxygen-depleted water, overland migration, high stocking density in aquaculture; warm water holds less O₂ so aeration critical in Nigeria. Osmoregulation: freshwater fish lose ions and gain water continuously; compensate by producing large quantities of dilute urine and actively absorbing ions through ionocytes on gill filaments. Ammonia: primary nitrogenous waste; excreted across gills; accumulates in poorly managed dense ponds; toxic to fish. Sensory systems: vision (wide-angle, colour in diurnal species); chemoreception (nostrils for smell, barbels and body surface taste buds; catfish locate feed by smell and barbel touch); lateral line (mechanoreceptors detect vibrations, prey, obstacles, darkness navigation); electroreception (mormyrids, Gymnarchus; weak electric field distortion detection). Reproduction: broadcast spawning (marine pelagic, many eggs, no care; bonga, mackerel); substrate spawning (few eggs, parental care; jewel fish); mouthbrooding (*O. niloticus*, female incubates 10-15 days; fewer eggs but higher survival). Clarias life cycle: rains trigger spawning; hormonal induction with Ovaprim in aquaculture; 10,000-50,000 eggs; hatch 18-24 hrs; yolk-sac 3-5 days; Artemia and fry feed; fingerlings 2-5 g in 3-4 weeks; grow-out 4-6 months to 500 g-1 kg. Tilapia: spawns year-round; monosex culture (methyltestosterone sex reversal) or predator control to prevent overcrowding; market weight 300-500 g in 5-7 months. Growth factors: temperature (catfish optimum 25-30 degrees Celsius); DO (>4 mg/L); feed quantity and quality (35-45% crude protein; FCR 1.2-1.8); genetics (improved strains 20-40% faster); sex (male tilapia faster); stocking density; disease status. Condition factor $K = 100W/L^3$.

Answers to Pilot Questions [Series 2]

Part 2.1: Classification and Taxonomy



1. Three major classes: Agnatha (jawless fish: lampreys and hagfish; no jaws, no paired fins, cartilaginous skeleton); Chondrichthyes (cartilaginous fish: sharks and rays; jaws present, cartilaginous skeleton, no swim bladder, skin with dermal denticles); Osteichthyes (bony fish: jaws, bony skeleton, usually a swim bladder, most have scales). Key difference between Chondrichthyes and Osteichthyes: Chondrichthyes have a cartilaginous skeleton and no swim bladder, while Osteichthyes have a bony skeleton and usually possess a swim bladder for buoyancy control.
2. Actinopterygii means "ray-finned fish"; the fins are supported by bony rays rather than fleshy lobes. All commercially important Nigerian fish belong to this subclass because: Actinopterygii is by far the largest group of bony fish, comprising over 30,000 species; all major Nigerian freshwater families (Clariidae, Cichlidae, Cyprinidae, Mormyridae) and marine families (Clupeidae, Sciaenidae, Lutjanidae) belong to this subclass; and the only alternatives within Osteichthyes are Sarcopterygii (lobe-finned fish: lungfish and coelacanth), which have no commercial importance in Nigerian fisheries.
3. Key characteristics of Clariidae: scaleless (naked) skin; four pairs of long barbels (one nasal, one maxillary, two mandibular pairs) used for chemosensory exploration; very long dorsal fin without a spine, running most of the body length; accessory air-breathing organ (tree-like arborescences) above the gills allowing respiration from atmospheric air; able to survive in oxygen-depleted water. Two species examples: *Clarias gariepinus* (African sharptooth catfish; most farmed species in Nigeria); *Heterobranchus longifilis* (African catfish with both a long dorsal fin AND a distinct adipose fin; often hybridised with *Clarias*).
4. Kingdom: Animalia; Phylum: Chordata; Class: Osteichthyes; Order: Siluriformes; Family: Clariidae; Genus: *Clarias*; Species: *gariepinus*. Scientific name: *Clarias gariepinus*.
5. Scientific names are more useful than common names because: a scientific name is unique (each species has exactly one accepted scientific name, universally recognised by scientists worldwide); common names vary by language, region, and community (*Clarias gariepinus* is called catfish in English, eja aro in Yoruba, aro in Igbo, tarwada in Hausa; without the scientific name, communication between researchers in different languages is ambiguous); different species may share the same common name (several species are



called "catfish" in Nigeria); and scientific names reflect evolutionary relationships (all members of the same genus share common ancestry, which has implications for similar biology, husbandry requirements, and disease susceptibility).

Part 2.2: External Morphology and Internal Anatomy

1. Any four: fusiform (streamlined, torpedo-shaped; adapted for fast swimming in open, flowing water; example: Nile perch *Lates niloticus* or mackerel *Scomber japonicus*); compressed (flattened side to side; adapted for manoeuvring in complex, slow, or still environments; example: Nile tilapia *Oreochromis niloticus*); depressed (flattened top to bottom; adapted for bottom-dwelling life, concealment, and ambush; example: some catfish and flatfish); elongated (eel-like, adapted for living in dense vegetation, rock crevices, or burrows; example: *Gymnarchus niloticus*).
2. Cycloid scales: smooth-edged with concentric growth rings; soft and flexible; feel smooth; found in soft-rayed fish; example family: Cyprinidae (carps, Labeo, Barbus). Ctenoid scales: have small spine-like projections (ctenii) on the posterior edge; feel rough when stroked from tail to head; found in spiny-rayed fish; example family: Cichlidae (tilapia, *Oreochromis*, Tilapia).
3. Five fin types and functions: (1) Dorsal fin: located on top of the body; function: provides stability against rolling and may deter predators (spiny anterior portion); (2) Anal fin: located on the underside behind the vent; function: stability and steering during swimming; (3) Caudal fin (tail fin): located at the posterior end; function: primary source of thrust for forward locomotion; shape reflects swimming style; (4) Pectoral fins: located behind the gill cover, one on each side; function: braking, turning, hovering, and fine steering; used for walking on substrate in some bottom-dwelling species; (5) Pelvic fins: located on the underside of the body; function: stability and steering.
4. The digestive system of a catfish (*Clarias*) consists of: the mouth (subterminal, used to pick up food from the substrate; barbels assist in locating food chemosensitively); oesophagus (short muscular tube); stomach (simple, J-shaped; less prominent than in some other fish); intestine (long and highly coiled; the length of the intestine relative to



body length reflects the diet; catfish are omnivores and have a moderately long intestine allowing sufficient time for digestion of plant material and detritus as well as animal food); and the accessory digestive glands (liver, producing bile stored in the gallbladder for fat emulsification; pancreas, producing digestive enzymes). Carnivorous fish (piscivores like Nile perch) have short, straight intestines because protein-rich animal food is digested rapidly; herbivores and omnivores have longer, more coiled intestines to allow more time for digestion of plant cell walls and starch.

5. The swim bladder is a gas-filled sac in the dorsal body cavity that regulates buoyancy by adjusting the volume of gas inside; this allows the fish to hover at any depth without expending energy on swimming. It is absent in Clariidae for two reasons related to their ecology and evolution: Clarias are bottom-dwelling fish that live in shallow, often oxygen-poor water and require direct contact with the substrate for feeding; a swim bladder would make it harder to remain on the bottom without constant swimming. More importantly, Clarias possess an accessory air-breathing organ as a primary buoyancy and oxygen-uptake mechanism; the evolutionary trajectory of the family moved toward air-breathing rather than a swim bladder for buoyancy, making the swim bladder unnecessary.

Part 2.3: Physiology of Aquatic Life

1. In the countercurrent exchange system of fish gills, water is pumped from the mouth across the gill lamellae and exits through the opercular opening. Blood flows through capillaries in the gill lamellae in the opposite direction to the water flow. This means that as oxygen is progressively extracted from the water as it flows over the lamellae, the blood receiving that oxygen is always flowing toward increasingly oxygen-rich water (from the fish's perspective). As a result, there is always an oxygen concentration gradient driving diffusion from water into blood throughout the entire length of the exchange surface, and blood leaving the gills can be almost fully saturated with oxygen even when starting with relatively low-oxygen water. If blood and water flowed in the same



direction, the gradient would equilibrate partway along the lamella and oxygen transfer would be far less efficient.

2. *Clarias gariepinus* possesses an accessory breathing organ located in the suprabranchial chamber above the gills. It consists of branching tree-like structures (arborescences) with a large surface area covered by a thin, richly vascularised epithelium that can absorb atmospheric oxygen. The fish rises to the water surface and gulps air; oxygen from the air diffuses across the arborescences into the blood. Aquaculture significance: (1) catfish can be farmed at much higher stocking densities than non-air-breathing species because they supplement gill respiration with air-breathing during low-oxygen periods; (2) catfish can survive transport overland for hours in moist conditions without oxygenated water, reducing mortality during live fish marketing; (3) catfish tolerate the low dissolved oxygen levels of poorly aerated earthen ponds, making them suitable for small-scale farmers without aeration equipment; (4) the air-breathing adaptation means stocking density is less limited by dissolved oxygen than by other factors such as feed and ammonia.
3. Freshwater fish live in water that is much more dilute than their body fluids (the body fluid osmolarity is approximately 300 mOsm/L while freshwater is approximately 1 to 5 mOsm/L). As a result: water continuously enters the fish by osmosis through the gills and thin skin; ions (sodium, chloride, calcium) are continuously lost by diffusion from the body into the surrounding water. To maintain homeostasis: the kidneys filter blood and produce large quantities of very dilute urine (removing excess water); and ionocytes (chloride cells) on the gill filaments actively transport ions from the surrounding water into the blood using energy (ATP), replacing the ions lost by diffusion. This active uptake requires energy and means freshwater fish are continuously expending energy on osmoregulation even when at rest.
4. Ammonia is the primary nitrogenous waste product of protein catabolism in freshwater fish; it is produced when amino acids from digested protein are deaminated in the liver. Ammonia is normally excreted harmlessly across the gill filaments into the surrounding water by diffusion along a concentration gradient (ammoniotelic excretion). In poorly managed fish ponds, ammonia toxicity arises when: the stocking density is too high, producing more ammonia from fish metabolism than the water volume can dilute; water



exchange is inadequate, allowing ammonia to accumulate; feed is overapplied, leaving uneaten feed to decompose and release additional ammonia; high pH (alkaline water) converts ammonia ($\text{NH}_3\text{-N}$) to the unionised, more toxic form NH_3 ; and high temperatures reduce the solubility of ammonia in water. At elevated ammonia concentrations (above 0.02 to 0.05 mg/L unionised NH_3), fish show respiratory distress, reduced feeding, and increased mortality.

5. Catfish chemosensory systems: nostrils (paired, non-connected to the pharynx; detect dissolved chemicals in the water, particularly attractants in feed and potential prey); barbels (four pairs: nasal, maxillary, and two mandibular pairs, covered with taste buds and mechanoreceptors; the fish uses them to probe the substrate and detect food in low-visibility conditions). Feeding management implications: (1) catfish locate pelleted feed primarily by smell from a distance and then confirm and pick up feed by tactile barbel exploration; therefore, feed must be water-stable enough to remain intact and release attractants while sinking to the substrate level where catfish feed; (2) the sinking rate of pellets is important: catfish are not surface feeders, so floating pellets used for tilapia are less appropriate; (3) the frequency and timing of feeding should take into account that catfish are predominantly nocturnal feeders; many farmers feed at dusk or dawn to coincide with peak feeding activity; (4) stressed catfish (from nets, vibration, light) may reject feed, so disturbance should be minimised around feeding time.

Part 2.4: Life Cycles and Reproduction

1. Oviparous: eggs laid and fertilised externally in the water; the most common strategy; example: *Clarias gariepinus* (eggs released into water during spawning, fertilised by male-shed sperm, develop externally in a hatchery trough). Ovoviviparous: eggs are retained inside the mother's body and hatched internally before release as live young; the embryo is nourished by the yolk sac rather than by the mother directly; example: some shark species entering Nigerian coastal waters. Mouthbrooding: eggs are fertilised and then immediately collected by one parent (usually the female) into the buccal cavity



where they are incubated; larvae are protected in the mouth for 10 to 15 days; example: Nile tilapia (*Oreochromis niloticus*).

2. In nature, *Clarias gariepinus* spawns at the onset of the rainy season (March to May in southern Nigeria) when rising water levels, warming temperatures, and flooding of terrestrial vegetation trigger hormonal changes that initiate gonad maturation and spawning behaviour. Males and females migrate to shallow flooded areas where spawning occurs at night with vigorous chasing and body contact. In hatchery conditions, natural spawning is replicated by: selecting mature broodstock (female with rounded, soft abdomen indicating ripe eggs; male with erect red papilla); stripping or injecting with hormones (carp pituitary extract at 0.5-0.7 mg/100g body weight, or synthetic Ovaprim at 0.5 mL/kg) to induce final oocyte maturation and ovulation; stripping eggs from the female by gentle abdominal massage; collecting sperm from the male by stripping the testes; combining eggs and sperm for fertilisation; incubating fertilised eggs in a hatchery trough with gentle water flow for 18 to 24 hours at 27 to 30 degrees Celsius.
3. Problem of early sexual maturation in tilapia: *Oreochromis niloticus* reaches sexual maturity at 4 to 6 months and as small as 50 to 100 g body weight; once mature, the fish reproduce frequently, producing large numbers of small offspring that compete with the farmed generation for feed and space; energy is diverted from somatic growth to reproduction; the pond becomes overstocked with stunted fish of unmarketable size. Method 1: monosex male culture by hormonal sex reversal (feeding fry with 17-alpha-methyltestosterone in feed at 60 mg/kg feed for 28 to 30 days post-hatching; differentiating gonads are permanently masculinised; resulting fish are all male and grow faster because they do not mouthbrood). Method 2: predator integration (stocking a few catfish or Nile perch in the tilapia pond to eat young tilapia fry and prevent overcrowding while not harming the larger tilapia grow-out fish).
4. Any five: temperature (catfish grow optimally at 25-30 degrees Celsius; below 20 degrees growth slows; below 15 degrees feeding ceases); dissolved oxygen (must remain above 4 mg/L for normal growth; below 2 mg/L growth slows and mortality risk rises); feed availability and quality (fish must receive adequate quantity of correctly formulated diet; 35-45% crude protein required; FCR 1.2-1.8 under good management); genetics (improved fast-growing strains can outperform local strains by 20-40%); sex (male tilapia



grow faster than females because females divert energy to mouthbrooding); stocking density (high density increases competition, stress, disease susceptibility, and reduces individual growth rates); disease status (parasites and pathogens redirect metabolic energy from growth to immune response and tissue repair).

5. Condition factor $K = (100 \times W) / L^3$, where W is the weight of the fish in grams and L is the total length in centimetres. The formula is derived from the assumption that for a fish of ideal proportions, weight should increase proportionally to the cube of length; the constant 100 is used to make the resulting value around 1.0 for most species. How it is used in pond management: a random sample of 30 to 50 fish is measured for weight and length; K values are calculated for each fish and averaged; if K is consistently above 1.5 for catfish, the fish are well-fed and healthy; if K falls below 1.0, the fish are thin for their length indicating underfeeding, overcrowding, disease, or poor water quality; the K value trend over successive sampling events (monthly or fortnightly) allows the farmer to detect management problems early and take corrective action before significant mortality or growth loss occurs.

References and Attributions [Series 2]

Textual References (Books and External Sources)

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Figures, Plates, Tables, and Boxes

- Table 2.1: Economically important Nigerian fish families Attribution: AI generated.
Suggested OER search string: "Nigerian fish families characteristics species aquaculture capture OER table".
- Figure 2.1: External morphology of a tilapia Attribution: AI generated. Suggested OER search string: "tilapia external morphology labelled diagram fins scales lateral line OER".
- Figure 2.2: Gill structure and countercurrent exchange Attribution: AI generated.
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- Figure 2.3: Life cycle of *Clarias gariepinus* in aquaculture Attribution: AI generated.
Suggested OER search string: "Clarias gariepinus aquaculture life cycle broodstock hatchery fingerlings grow-out OER".



Course code: AGE 308

Course title: Fish Farming and Management

Series 3: Principles and Practices of Fish Farming

- **Part 3.1: Types of Aquaculture Systems**

- Sub Part 3.1.1: Extensive, semi-intensive, and intensive systems
- Sub Part 3.1.2: Pond types and their characteristics
- Sub Part 3.1.3: Other culture systems: cages, tanks, raceways, and RAS

- **Part 3.2: Site Selection and Pond Construction**

- Sub Part 3.2.1: Criteria for site selection
- Sub Part 3.2.2: Pond design and construction
- Sub Part 3.2.3: Water supply and pond management infrastructure

- **Part 3.3: Hatchery Operations and Fingerling Production**

- Sub Part 3.3.1: Broodstock management and conditioning
- Sub Part 3.3.2: Spawning induction and egg incubation
- Sub Part 3.3.3: Larval rearing and fingerling production

- **Part 3.4: Feeding, Water Quality, and Disease Management**

- Sub Part 3.4.1: Fish nutrition and feed formulation
- Sub Part 3.4.2: Water quality parameters and management
- Sub Part 3.4.3: Disease prevention and treatment



Introduction

Successful fish farming requires converting biological knowledge into practical management decisions. Choosing the right culture system, selecting an appropriate site, constructing a functional pond, operating a hatchery, formulating nutritious feed, maintaining water quality, and preventing disease are the core practical competencies of a fish farmer. This Series covers each of these competencies in the context of Nigerian aquaculture, with particular emphasis on African catfish (*Clarias gariepinus*) and Nile tilapia (*Oreochromis niloticus*), the two dominant farmed species.

We begin with the types of aquaculture systems available to Nigerian farmers, cover site selection and pond construction, move through hatchery operations and fingerling production, and conclude with the management of feed, water quality, and fish health. The content is practical and directly applicable to the operation of a school fish pond or a small commercial fish farm.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 3.1** describe the characteristics of extensive, semi-intensive, and intensive aquaculture systems and identify the system appropriate for a given context (Linked to Part 3.1),
- **SLO 3.2** describe the types of aquaculture pond and other culture systems used in Nigeria (Linked to Part 3.1),
- **SLO 3.3** apply the criteria for site selection for a fish farm and describe the steps in pond design and construction (Linked to Part 3.2),
- **SLO 3.4** describe broodstock management, spawning induction, egg incubation, and larval rearing for *Clarias gariepinus* (Linked to Part 3.3),



- **SLO 3.5** explain the nutritional requirements of catfish and tilapia and describe the principles of feed formulation (Linked to Part 3.4),
- **SLO 3.6** describe the key water quality parameters in fish farming and explain how to manage them (Linked to Part 3.4), and
- **SLO 3.7** identify the major diseases of farmed catfish and tilapia and describe prevention and treatment strategies (Linked to Part 3.4).

3.1 Types of Aquaculture Systems

3.1.1 Extensive, semi-intensive, and intensive systems

Aquaculture systems are classified by the intensity of management and inputs applied. Extensive systems rely on natural productivity of the water (phytoplankton, zooplankton, insects, and detritus) to feed the fish; no supplementary feed is used; stocking densities are very low (less than 1,000 fish per hectare); yields are low (less than 500 kg per hectare per year); capital investment is minimal. Extensive aquaculture is practised in large earthen ponds fertilised with organic manure (poultry litter, cow dung) and is the dominant system in rice-fish culture and subsistence village ponds in northern Nigeria.

Semi-intensive systems combine natural productivity (enhanced by fertilisation) with supplementary pelleted or farm-made feed; stocking densities are moderate (1,000 to 10,000 fish per hectare); yields range from 1,000 to 5,000 kg per hectare per year; most school fish ponds and small commercial ponds in Nigeria operate at this level. Intensive systems use complete manufactured feeds with no reliance on natural productivity; high stocking densities (10,000 to 200,000 fish per hectare or higher in tanks); yields of 20,000 to 100,000 kg per hectare per year; require aeration, water exchange, and careful management; characteristic of large commercial catfish farms in south-western Nigeria using concrete tanks or raceways.

Fill in the blank: Semi-intensive aquaculture systems combine natural _____ (enhanced by fertilisation) with supplementary feed and achieve yields of 1,000 to 5,000 kg per hectare per year.



3.1.2 Pond types and their characteristics

The earthen pond is the most common aquaculture facility in Nigeria. It is constructed by excavating soil to form the pond basin or by building earthen embankments (levees) to retain water. Key structural components include: the inlet structure (controls water inflow; pipe or notch in the embankment); the outlet structure (monk or stand-pipe; allows draining and water level control); the overflow spillway (prevents embankment overtopping during heavy rain); the freeboard (the height of embankment above the maximum water level, typically 0.3 to 0.5 m to prevent wave overtopping); and anti-seepage measures (clay lining, compaction, or plastic sheeting to reduce seepage losses in sandy soils).

Concrete ponds (circular or rectangular) are used in intensive systems; they can be cleaned and disinfected between crops, have no seepage, and allow precise control of stocking and harvesting. Hapas are fine-mesh net enclosures suspended in a pond, used for nursing larvae and fry before stocking into grow-out ponds. Tarpaulin or collapsible ponds (HDPE liners in frames or excavated pits) are increasingly popular among urban and peri-urban catfish farmers in Nigeria because they can be installed on any flat surface, have no seepage, and can be relocated. Each pond type has different construction costs, operational requirements, and suitability for different production scales.

Fill in the blank: The _____ pond is the most common aquaculture facility in Nigeria; key structural components include an inlet structure, outlet structure, overflow spillway, freeboard, and anti-seepage measures.



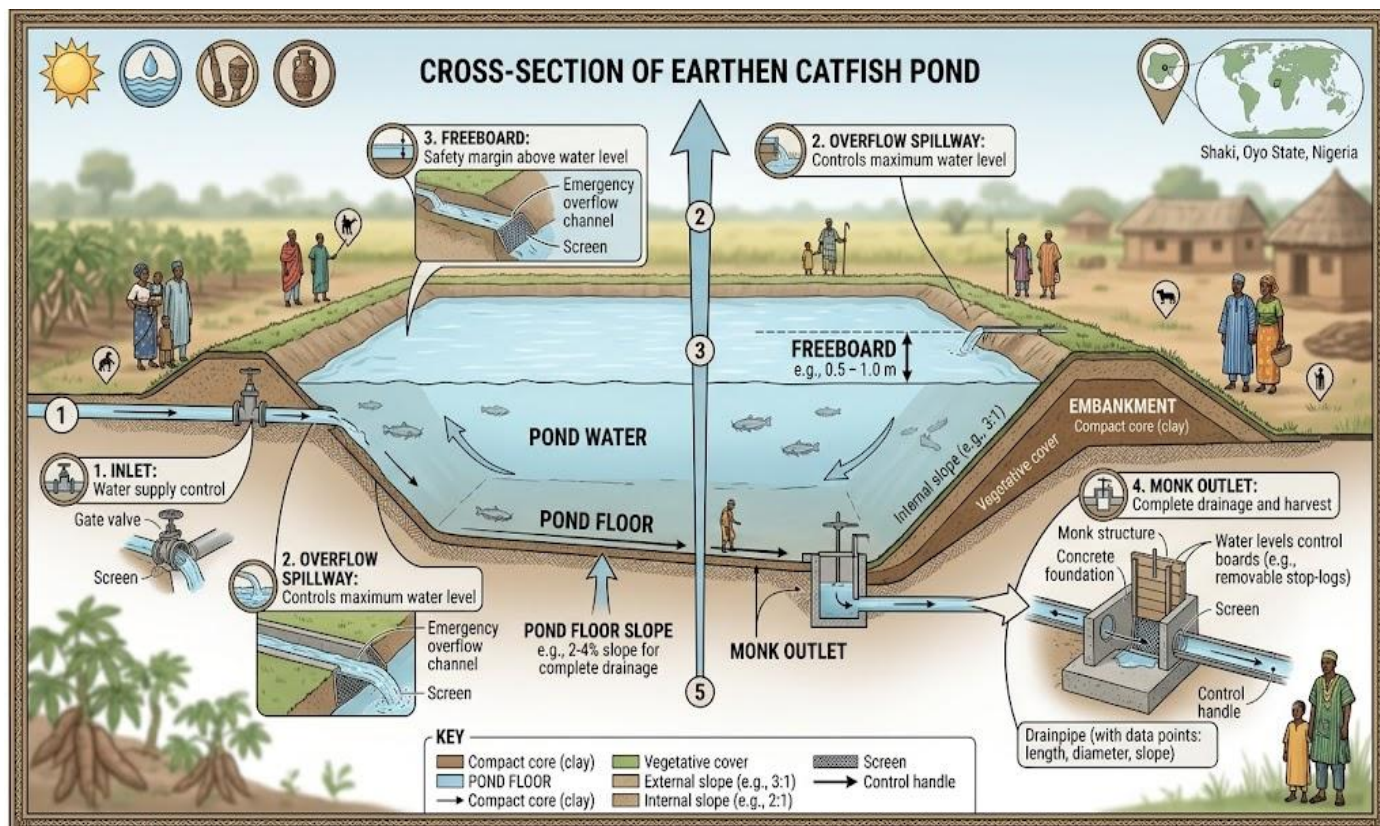


Figure 3.1: Cross-section diagram of a typical earthen catfish pond showing structural components

3.1.3 Other culture systems: cages, tanks, raceways, and RAS

Cage culture involves suspending net cages in a natural or man-made water body (reservoir, lake, or river) and stocking fish at high density; the natural water current provides oxygenation and removes waste; feed is introduced into the cage. Cage culture is practised on Kainji, Jebba, and Shiroro reservoirs in Nigeria for tilapia and catfish. Advantages: low construction cost, good water quality from flowing water, large water bodies usable. Disadvantages: risk of flooding or cage damage; disease spread between cages; not suitable for broodstock management or juvenile rearing.

Raceways are long, narrow concrete or fibreglass channels through which water flows continuously at a controlled rate; high stocking densities are possible because fresh oxygenated water is continuously supplied and waste removed. Recirculating Aquaculture Systems (RAS) reuse water by passing it through a biofilter (to remove ammonia by nitrification), a mechanical



filter (to remove suspended solids), an aeration or oxygenation unit, and a UV steriliser (to reduce pathogens), then returning treated water to the fish tanks. RAS allows the highest stocking densities and production per unit area of any system, uses minimal water, and can be operated in any location including urban areas; the high capital and operating costs currently limit RAS adoption to large commercial operators in Nigeria.

Fill in the blank: Recirculating Aquaculture Systems (RAS) reuse water by passing it through a _____ (to remove ammonia), a mechanical filter, aeration, and UV sterilisation before returning it to the fish tanks.

Pilot questions 3.1

1. Distinguish between extensive, semi-intensive, and intensive aquaculture systems in terms of stocking density, feed input, and yield.
2. Name the key structural components of an earthen fish pond and state the function of each.
3. Explain the advantages and disadvantages of cage culture for Nigerian reservoirs.
4. Explain what a RAS is and state one advantage and one limitation of RAS for Nigerian aquaculture.
5. Explain what a hapa is and describe its use in catfish production.

3.2 Site Selection and Pond Construction

3.2.1 Criteria for site selection

Selecting the correct site is the most important decision in establishing a fish farm, as a poor site cannot be corrected after construction. Key criteria are: water availability (a perennial, reliable water source of adequate flow to fill the pond and compensate for losses through seepage and evaporation; the source may be a stream, river, borehole, spring, or reservoir; seasonal streams are unreliable); water quality (the source water should be free of pesticides, industrial effluents,



and excessive turbidity; pH 6.5 to 8.5, dissolved oxygen above 5 mg/L, low ammonia and nitrite); and soil suitability (the soil must have sufficient clay content to hold water; a minimum of 20 to 30 per cent clay is required; sandy soils require expensive lining).

Additional criteria: topography (a gentle slope of 0.5 to 2 per cent is ideal for drainage by gravity and to enable pond construction without excessive earth-moving; flat land requires levelling; steep slopes require terracing and are expensive); land tenure and security (the farmer must have secure rights to the land for the long term); proximity to market (closer to market reduces transport cost and fish mortality during live transport); access to inputs (feed, fingerlings, equipment, and technical support must be accessible); and infrastructure (roads, electricity, and communication for operational management). In Nigeria, water availability during the dry season is the most commonly limiting factor in inland aquaculture site selection.

Fill in the blank: Soil suitability for earthen pond construction requires a minimum of 20 to 30 per cent _____ content to hold water; sandy soils require expensive lining or concrete construction.

3.2.2 Pond design and construction

Pond design begins with a site survey to determine the topography, soil type, water source location, and access. A pond layout is drawn showing the positions of ponds, inlet and outlet structures, access roads, and storage facilities. Standard dimensions for a grow-out catfish pond: surface area 200 to 2,000 m²; depth 1.2 to 1.5 m (to maintain adequate water volume and temperature stability); embankment top width 0.5 to 1.0 m; embankment side slopes 1:1.5 to 1:2 (horizontal to vertical). The pond should be positioned so that the inlet is at the highest point and the outlet (monk) at the lowest point to allow complete drainage by gravity.

Construction sequence: (1) clear and strip vegetation from the pond area; (2) survey and stake the embankment positions; (3) excavate the pond basin, using the excavated soil to form the embankments; (4) compact the embankments in layers using a roller or hand tamping; (5) install the inlet pipe with a screen to exclude wild fish; (6) install the monk outlet structure; (7) construct the spillway at the correct elevation; (8) allow embankments to settle for several weeks before filling; (9) lime the pond floor with agricultural lime (1 to 2 tonnes per hectare) to



disinfect and raise pH; (10) fill the pond and allow natural fertilisation to develop before stocking. A school fish pond of 50 to 200 m² follows the same principles at a smaller scale.

Fill in the blank: The monk outlet structure is installed at the _____ point of the pond floor to allow complete drainage by gravity; the inlet pipe is installed at the highest point with a screen to exclude wild fish.

<u>Parameter</u>	<u>Commercial Catfish Grow-out Pond</u>	<u>School Fish Pond</u>
Location	Accessible site with reliable water source, good drainage	Within school compound, safe and accessible for students
Size/Area	400–800 m ² per pond (depending on scale)	20–50 m ² (small demonstration pond)
Depth	1.2–1.5 m	0.8–1.0 m
Water Supply	Borehole, stream, or reservoir with inlet/outlet structures	Tap water, borehole, or small storage tank
Stocking Density	10–15 fish/m ² (intensive system)	5–8 fish/m ² (moderate, for learning purposes)
Feeding System	Formulated commercial feeds, regular feeding schedules	Simple feeding with pellets or farm-made feed
Reproduction	Not usually done in grow-out ponds; fingerlings sourced from hatcheries	Demonstration of breeding possible in small tanks or hapas
Species	African catfish (<i>Clarias gariepinus</i> , <i>Heterobranchus spp.</i>)	African catfish (<i>Clarias gariepinus</i>)
Yield	5–10 tons/ha per cycle under good management	50–100 kg per cycle (educational use)
Sustainability/Use	Commercial production for market sales	Educational training, demonstration, and small-scale consumption

Table 3.1: Standard dimensions and design parameters for catfish grow-out and school fish ponds



3.2.3 Water supply and pond management infrastructure

The water supply system must deliver adequate flow to fill the pond within a reasonable time and to compensate for daily losses. A typical earthen pond loses 2 to 10 mm of water per day through seepage and evaporation; a 1,000 m² pond with 5 mm daily loss requires 5,000 litres (5 m³) per day minimum inflow. Water supply structures include: gravity-fed intake from a stream (screened to exclude wild fish and debris), motorised pump from a borehole or river, or rainwater collection. Water storage tanks or header tanks provide a buffer supply for RAS or tank systems.

Management infrastructure includes: a tool store and feed store (dry, secure, with pallets to keep feed bags off the damp floor); a generator for emergency aeration and pumping; aerators (paddle-wheel or diffuser types for intensive ponds); fish holding tanks for grading, treatment, and live marketing; a weighing scale and measuring board for fish sampling; a water quality testing kit (thermometer, dissolved oxygen meter or Winkler kit, pH meter or strips, ammonia test kit); and farm records (stocking register, feeding log, water quality log, mortality log, and harvest record). Good record-keeping is the difference between managing a fish farm scientifically and guessing.

Fill in the blank: A 1,000 m² earthen pond losing 5 mm of water per day through seepage and evaporation requires a minimum inflow of _____ litres (5 m³) per day to maintain water level.

Pilot questions 3.2

1. List six criteria for selecting a site for a fish farm and briefly explain the most important one.
2. Describe the standard dimensions of a catfish grow-out pond.
3. Describe the construction sequence for an earthen fish pond.
4. Explain the function of liming the pond floor before first filling.
5. State five items of farm infrastructure required for managing a commercial catfish farm.

3.3 Hatchery Operations and Fingerling Production

3.3.1 Broodstock management and conditioning



Broodstock are the adult fish kept specifically to produce eggs and sperm for the hatchery. For *Clarias gariepinus*, broodstock selection criteria are: size (females of at least 500 g to 1.5 kg preferred; males of 300 g to 1 kg); age (one to three years old); body condition (plump, well-formed, no deformities, no fin damage, no disease signs); and genetic diversity (avoid selecting only from a single family or closely related fish to prevent inbreeding depression). The female-to-male broodstock ratio is typically 2:1 to 3:1 because males are used repeatedly while each female needs recovery time between spawnings.

Broodstock conditioning involves maintaining broodstock in separate, well-managed ponds or tanks with: a high-quality diet (35 to 45 per cent crude protein feed fed at 2 to 3 per cent body weight per day); clean, well-oxygenated water (dissolved oxygen above 5 mg/L; water exchange of 20 to 30 per cent per day in tanks); and stress avoidance (minimise handling and disturbance). Condition is assessed monthly by checking the condition factor K; females approaching readiness show a swollen, rounded abdomen and can be confirmed by inserting a soft catheter to extract a small sample of eggs (cannulation); ripe eggs are large, round, and uniformly amber-coloured.

Fill in the blank: Female catfish broodstock approaching spawning readiness show a swollen, rounded abdomen; readiness is confirmed by _____, inserting a soft catheter to extract a small egg sample which should be round, large, and amber-coloured.

3.3.2 Spawning induction and egg incubation

Clarias gariepinus does not spontaneously spawn in captivity; hormonal induction is required. The standard method uses carp pituitary extract (CPE) at 0.5 to 0.7 mg per 100 g female body weight, or Ovaprim (salmon GnRH analogue + domperidone) at 0.5 mL per kg body weight, or human chorionic gonadotropin (hCG) at 500 to 1,000 IU per kg. The hormone is injected intramuscularly or intraperitoneally at the base of the dorsal fin. Ovulation occurs 8 to 12 hours after injection at 27 to 28 degrees Celsius. The female is then anaesthetised (using clove oil or MS-222), eggs are stripped by gentle massage of the abdomen into a dry bowl, sperm is obtained by dissecting the testes, and both are mixed thoroughly (dry method of fertilisation).



Fertilised eggs are spread thinly in incubation troughs or kakaban (bundles of palm fronds or plastic mesh used as egg substrate). Water flow is maintained gently over the eggs to supply oxygen and remove metabolic waste. Eggs hatch in 18 to 24 hours at 27 to 30 degrees Celsius. Dead (white, opaque) eggs are removed by siphoning to prevent fungal infection spreading to live eggs. Hatching rates in well-managed hatcheries range from 60 to 90 per cent. The newly hatched larvae are transparent with a large yolk sac; they remain in the hatchery trough for 3 to 5 days until the yolk sac is absorbed and exogenous feeding begins.

Fill in the blank: Fertilised eggs of *Clarias gariepinus* hatch in 18 to 24 hours at 27 to 30 degrees Celsius; dead eggs appear _____ and opaque and must be removed by siphoning to prevent fungal spread.

[Insert Figure here] Short description: Flowchart showing: broodstock selection and conditioning; hormonal induction (CPE or Ovaprim injection); egg stripping and fertilisation (dry method); egg incubation in troughs (18-24 hrs); yolk-sac larval stage (3-5 days); exogenous feeding on *Artemia*; nursery pond stocking; fingerling (2-5 g) production in 3-4 weeks. Caption: Figure 3.2: Flowchart of catfish hatchery operations from broodstock selection to fingerling production Sample AI prompt: "Generate a hatchery operations flowchart from broodstock to fingerling for *Clarias gariepinus*." Suggested OER search string: "catfish hatchery operations flowchart broodstock hormone spawning fingerling OER".

3.3.3 Larval rearing and fingerling production

Larval rearing begins when the yolk sac is absorbed (day 3 to 5 post-hatch) and the larvae begin swimming actively and searching for food. The first feed is *Artemia* (brine shrimp) nauplii, which are hatched from cysts in saline water (25 to 35 ppt) for 24 hours; nauplii are nutritionally rich, appropriately sized for small larvae, and stimulate predatory feeding behaviour. Larvae are also fed finely ground commercial starter feed at least four times per day. Feeding frequency is high (4 to 8 times per day) because larvae have small stomachs and high metabolic rates; uneaten feed accumulates quickly and degrades water quality, so feed input must be carefully calibrated.

Larvae are reared in indoor tanks or hatchery troughs for the first 2 to 3 weeks, then progressively transitioned to outdoor nursery ponds. Cannibalism is a serious problem in catfish



larvae from about day 10 onwards: larger larvae actively prey on smaller ones; grading (sorting fish by size using grading nets with different mesh sizes) is essential at least twice per week to reduce size variation and cannibalism losses. By 3 to 4 weeks post-hatch, juveniles reach fingerling size (2 to 5 g), which is the standard stocking size for grow-out ponds. Fingerling production cost and quality are critical to overall farm profitability; poor fingerlings with high size variation produce uneven batches at harvest.

Fill in the blank: Cannibalism in catfish larvae begins from about day 10 post-hatch; _____ (sorting by size using grading nets) is performed at least twice per week to reduce size variation and prevent larger larvae eating smaller ones.

Pilot questions 3.3

1. State the broodstock selection criteria for female *Clarias gariepinus*.
2. Describe the hormonal induction procedure for spawning *Clarias gariepinus* in the hatchery.
3. Describe the dry method of fertilisation of catfish eggs.
4. Explain why grading is critical in catfish larval rearing.
5. Describe the transition from *Artemia* feeding to pelleted feed in catfish larval rearing.

3.4 Feeding, Water Quality, and Disease Management

3.4.1 Fish nutrition and feed formulation

The nutritional requirements of catfish and tilapia differ in protein requirement and digestive capability. *Clarias gariepinus* is omnivorous with a preference for animal protein; it requires 35 to 45 per cent crude protein in the diet for optimal growth (lower protein requirements at larger sizes). *Oreochromis niloticus* is a filter-feeder and omnivore that can utilise plant protein efficiently; it requires 25 to 35 per cent crude protein. Essential amino acids (lysine, methionine, tryptophan) must be supplied in adequate quantities; most plant protein sources are deficient in methionine, which must be supplemented. Energy content of the diet affects protein utilisation:



insufficient dietary energy causes protein to be catabolised for energy rather than used for growth.

Common feed ingredients used in Nigeria: protein sources (fishmeal, soyabean meal, groundnut cake, blood meal, poultry by-product meal, maggot meal); energy sources (maize, sorghum, wheat offal, cassava); vitamin and mineral premix; binding agents (wheat flour, cassava starch) to improve pellet water stability. Feed conversion ratio (FCR): the amount of feed (kg) required to produce 1 kg of fish. Good FCR for catfish is 1.2 to 1.8; for tilapia 1.5 to 2.0. FCR above 2.5 indicates overfeeding, poor feed quality, or poor management. Daily feed allowance is 3 to 5 per cent of total fish biomass per day for juveniles, decreasing to 1.5 to 2.5 per cent for larger fish.

Fill in the blank: The daily feed allowance for juvenile catfish is 3 to 5 per cent of total fish _____ per day, decreasing to 1.5 to 2.5 per cent as fish grow larger.

3.4.2 Water quality parameters and management

The key water quality parameters for catfish and tilapia ponds are: temperature (optimal 25 to 30 degrees Celsius; below 18 degrees feeding stops; avoid exceeding 33 degrees); dissolved oxygen (DO; optimal above 5 mg/L; below 4 mg/L growth slows; below 2 mg/L emergency aeration or water exchange required; catfish survive to near-zero DO by air-breathing); pH (optimal 6.5 to 8.5; below 5.0 kills fish; above 9.5 kills fish through ammonia conversion); total ammonia nitrogen (TAN; should be below 0.02 mg/L unionised NH_3 ; rises with high stocking density, overfeeding, and poor water exchange); and nitrite (NO_2 ; toxic above 0.5 mg/L; produced during incomplete nitrification in biofilters).

Management practices: water exchange (replace 10 to 30 per cent of pond water per day in intensive earthen ponds; more in tanks); aeration (paddle-wheel or air diffuser aerators in intensive ponds, especially at night when DO falls due to respiration and photosynthetic DO production ceases); liming (apply agricultural lime at 50 to 100 kg per hectare when pH falls below 6.5 to restore buffering capacity); feed management (avoid overfeeding; remove uneaten feed; feed at fixed times to allow monitoring of feed consumption); stocking density control (reduce stocking if DO or ammonia are chronically problematic). Water quality testing using a



simple kit or meter should be done at least twice weekly; early morning readings are most critical as DO is lowest after a night of respiration.

Fill in the blank: Dissolved oxygen in catfish ponds should remain above _____ mg/L for optimal growth; early morning readings are most critical because DO is lowest after a night of respiration with no photosynthesis.

<u>Parameter</u>	<u>Optimal Range</u>	<u>Critical Limits</u>	<u>Effects on Fish</u>	<u>Corrective Actions</u>
Temperature	Catfish: 26–30°C; Tilapia: 25–28°C	<20°C or >35°C	Reduced feeding, slow growth, stress, mortality	Adjust water depth, provide shade, aeration, or heating
Dissolved Oxygen (DO)	>5 mg/L	<3 mg/L	Stress, poor growth, suffocation, mortality	Aeration, water exchange, reduce stocking density
pH	6.5–8.0	<5.5 or >9.0	Stress, poor feed conversion, reduced survival	Lime acidic ponds, add buffer for alkaline ponds
Ammonia (NH₃)	<0.02 mg/L	>0.05 mg/L	Toxicity, gill damage, reduced growth, mortality	Reduce feeding, water exchange, biofiltration
Nitrite (NO₂⁻)	<0.1 mg/L	>0.5 mg/L	Brown blood disease, reduced oxygen transport	Salt addition, water exchange, improve biofilter
Transparency (Secchi depth)	30–40 cm	<20 cm or >60 cm	Poor feeding efficiency, algal bloom or low productivity	Adjust fertilization, manage plankton balance
Hardness	50–150 mg/L CaCO ₃	<20 mg/L	Poor buffering, stress, reduced growth	Add lime or gypsum to increase hardness



Table 3.2: Water quality parameters for catfish and tilapia ponds: optimal ranges and critical limits

3.4.3 Disease prevention and treatment

Disease prevention is far more cost-effective than treatment in fish farming. Prevention strategies include: biosecurity (prevent introduction of pathogens through wild fish, infected fingerlings, or contaminated equipment); good water quality management (most bacterial and fungal diseases are secondary to stress caused by poor water quality; maintaining DO, pH, and ammonia within optimal ranges dramatically reduces disease incidence); proper stocking density (overcrowding increases stress, physical injury, and pathogen transmission); quarantine of new fish (hold new fingerlings in a separate facility for 7 to 14 days and observe for disease signs before stocking into the main system); and use of healthy, disease-free fingerlings from certified hatcheries.

Common diseases of catfish and tilapia in Nigeria: bacterial diseases (motile *Aeromonas* septicaemia: skin ulcers, haemorrhage, abdominal bloating; treated with oxytetracycline or florfenicol in feed); Columnaris disease (*Flavobacterium columnare*: cotton-wool lesions on skin and gills; treated with salt baths or oxytetracycline); fungal diseases (*Saprolegnia*: white cotton-like growth on skin and eggs; treated with potassium permanganate or salt baths); parasitic diseases (*Ichthyophthirius multifiliis* "white spot" or ich: white cysts on skin and gills; treated with salt baths or formalin dips; *Dactylogyrus* and *Gyrodactylus* gill flukes: treated with praziquantel in feed or baths); and nutritional diseases (vitamin C deficiency causing scoliosis; corrected by vitamin premix supplementation).

Fill in the blank: Motile *Aeromonas* septicaemia causes skin _____, haemorrhage, and abdominal bloating in catfish; it is treated with oxytetracycline or florfenicol added to the feed.

<u>Measure</u>	<u>Explanation</u>
Water quality management	Maintain optimal temperature, pH, and dissolved oxygen; regular monitoring prevents stress and disease outbreaks.
Stocking density control	Avoid overcrowding; high densities increase stress, competition, and disease transmission.



Biosecurity practices	Restrict farm access, disinfect equipment, and prevent introduction of infected fish from outside sources.
Quality feed and feeding practices	Use balanced, non-contaminated feeds; avoid overfeeding to reduce water pollution and pathogen growth.
Quarantine of new stock	Isolate new fingerlings before introduction to main ponds to prevent spread of pathogens.
Regular health monitoring	Observe fish behavior, feeding response, and physical signs daily to detect early disease symptoms.
Vaccination and prophylaxis	Where available, use vaccines or preventive treatments against common pathogens.
Proper waste management	Remove excess feed and organic waste to reduce pathogen load in ponds.

Box 3.1: Disease prevention checklist for a Nigerian catfish farm

Pilot questions 3.4

1. State the crude protein requirement for catfish and tilapia and explain why they differ.
2. Calculate the daily feed amount for a pond containing 500 catfish averaging 200 g each, at a feeding rate of 3 per cent body weight.
3. Describe five water quality management practices for an intensive catfish pond.
4. Identify three common diseases of catfish and tilapia in Nigeria, state their causative agent, signs, and treatment.
5. Explain five disease prevention strategies that a catfish farmer should implement.



Series Summary

This Series covered the principles and practices of fish farming in Nigeria. We described the three intensity levels of aquaculture systems (extensive, semi-intensive, intensive), the types of culture facilities (earthen ponds, concrete ponds, hapas, tarpaulin ponds, cages, raceways, RAS), and site selection criteria (water availability, water quality, soil suitability, topography, tenure, market access). We covered pond design (dimensions, embankment slopes, monk outlet, freeboard) and construction (ten-step sequence), and the infrastructure needed for operational management.

We covered hatchery operations for *Clarias gariepinus*: broodstock conditioning and selection, hormonal induction with CPE or Ovaprim, the dry fertilisation method, egg incubation (18 to 24 hours at 27 to 30 degrees Celsius), yolk-sac larval stage, *Artemia* feeding, grading to control cannibalism, and fingerling production. Finally, we covered feeding management (35 to 45 per cent crude protein for catfish, FCR 1.2 to 1.8, daily ration 3 to 5 per cent body weight), water quality parameters and management (DO, pH, temperature, ammonia, nitrite), and disease management (prevention through biosecurity and water quality; treatment of bacterial, fungal, and parasitic diseases). By completing this Series, you should be able to achieve all seven Series Learning Outcomes (SLO 3.1 to SLO 3.7).

Glossary of Terms

- **Aeration:** the addition of oxygen to pond water using paddle-wheel aerators, air blowers, or diffusers; critical in intensive systems and at night when photosynthesis is absent.
- **Artemia:** brine shrimp whose nauplii are used as the first live feed for catfish larvae immediately after yolk-sac absorption; hatched from cysts in saline water.
- **Biofilter:** a filter containing bacteria (mainly *Nitrosomonas* and *Nitrobacter*) that oxidise toxic ammonia to nitrite and then to relatively harmless nitrate; essential in RAS.



- **Biosecurity:** the set of measures taken to prevent the introduction and spread of pathogens into a fish farm; includes quarantine, disinfection of equipment, and use of disease-free fingerlings.
- **Cannibalism:** the killing and eating of smaller fish by larger fish of the same species; a major cause of mortality in catfish larvae from about day 10 post-hatch.
- **Cannulation:** the insertion of a soft catheter into the urogenital pore of a female fish to extract a small egg sample for maturity assessment; used in broodstock management.
- **Carp pituitary extract (CPE):** a hormone preparation extracted from carp pituitaries containing gonadotropins; used to induce spawning in *Clarias gariepinus*; standard dose 0.5-0.7 mg per 100 g female body weight.
- **Condition factor (K):** $K = 100W/L^3$; a measure of fish plumpness relative to length; used to assess nutritional condition of broodstock and grow-out fish.
- **Earthen pond:** a fish pond constructed by excavating soil to form the basin or building earthen embankments to retain water; the most common aquaculture facility in Nigeria.
- **Extensive aquaculture:** a low-input system relying on natural pond productivity; no supplementary feed; low stocking density; yields below 500 kg per hectare per year.
- **Feed conversion ratio (FCR):** kilograms of feed required to produce 1 kg of fish body weight; lower is better; catfish FCR target 1.2-1.8.
- **Freeboard:** the height of the pond embankment above the maximum water level; typically 0.3-0.5 m to prevent wave overtopping and embankment failure.
- **Grading:** the sorting of fish by size using grading nets with calibrated mesh sizes; performed regularly in catfish larval rearing to reduce size variation and cannibalism.
- **Hapa:** a fine-mesh net enclosure suspended in a pond; used for nursing catfish larvae and fry before stocking into grow-out ponds.
- **Hormonal induction:** the use of gonadotropic hormones (CPE, Ovaprim, hCG) to stimulate final oocyte maturation and ovulation in captive broodstock.



- **Intensive aquaculture:** a high-input system using complete manufactured feeds, high stocking densities (>10,000 fish per hectare), aeration, and careful water quality management; yields >20,000 kg per hectare per year.
- **Monk outlet:** a vertical stand-pipe outlet structure in an earthen pond; water level is controlled by adding or removing boards; allows complete drainage of the pond.
- **Ovaprim:** a synthetic spawning hormone preparation (salmon GnRH analogue + domperidone); standard dose 0.5 mL per kg female body weight; widely used for catfish hatchery induction.
- **RAS (Recirculating Aquaculture System):** a closed or semi-closed aquaculture system in which water is reused after treatment through biofilters, mechanical filters, aeration, and UV sterilisation.
- **Semi-intensive aquaculture:** a system combining natural pond productivity with supplementary feed; moderate stocking density; yields 1,000-5,000 kg per hectare per year.
- **Spillway:** an overflow structure in a pond embankment that allows excess water to exit safely without eroding the embankment; set at the maximum desired water level.
- **Tarpaulin (collapsible) pond:** an HDPE-lined pond in a frame or pit; no seepage; relocatable; popular among urban and peri-urban catfish farmers in Nigeria.
- **Total ammonia nitrogen (TAN):** the total ammonia in water including both ionised (NH_4^+) and unionised (NH_3) forms; the unionised form is toxic above 0.02-0.05 mg/L.
- **White spot (*Ichthyophthirius multifiliis*):** a freshwater parasitic protozoan causing white cysts on fish skin and gills; treated with salt baths or formalin dips.
- **Yolk-sac larva:** a newly hatched fish larva that has not yet begun exogenous feeding; nourished by nutrients in the yolk sac for 3-5 days post-hatch.

Concept Check Questions [Series 3]



Objective Questions

1. Intensive aquaculture uses complete manufactured feeds, high stocking densities, and _____, achieving yields of 20,000 kg per hectare per year or more. (Linked to SLO 3.1)
2. The key structural component that allows complete drainage of an earthen pond is the _____ outlet structure, which controls water level with removable boards. (Linked to SLO 3.2)
3. Hormonal induction in *Clarias gariepinus* uses carp pituitary extract or _____ (salmon GnRH analogue + domperidone) injected at 0.5 mL per kg female body weight. (Linked to SLO 3.4)
4. Catfish larvae require _____ (brine shrimp nauplii) as their first live feed immediately after yolk-sac absorption. (Linked to SLO 3.4)
5. Dissolved oxygen in catfish ponds should remain above _____ mg/L for optimal growth; early morning readings are most critical. (Linked to SLO 3.6)

Short-Answer Questions

- Distinguish between extensive, semi-intensive, and intensive aquaculture systems. (Linked to SLO 3.1)
- List six criteria for fish farm site selection. (Linked to SLO 3.3)
- Describe the broodstock selection criteria for female catfish and explain cannulation. (Linked to SLO 3.4)
- State the crude protein requirements for catfish and tilapia and give three protein feed ingredients used in Nigeria. (Linked to SLO 3.5)
- Name three common diseases of catfish, state the causative agent and main clinical sign, and state the treatment for each. (Linked to SLO 3.7)

Long-Answer Questions

1. Describe the types of aquaculture systems and culture facilities used in Nigeria, covering extensive, semi-intensive, and intensive systems, earthen ponds, concrete ponds, cage culture, and RAS. (Linked to SLOs 3.1, 3.2)



2. Describe the criteria for site selection, the design and construction sequence of an earthen catfish pond, and the management infrastructure needed for a commercial catfish farm. (Linked to SLO 3.3)
3. Describe the complete hatchery operations for *Clarias gariepinus* from broodstock conditioning through spawning induction, egg incubation, larval rearing, and fingerling production, and explain feeding management, water quality parameters, and disease prevention strategies for grow-out ponds. (Linked to SLOs 3.4, 3.5, 3.6, 3.7)

Answers to Concept Check Questions [Series 3]

Objective Questions

6. Aeration.
7. Monk.
8. Ovaprim.
9. Artemia.
10. 5.

Short-Answer Questions

11. Extensive: no supplementary feed, natural productivity only, stocking <1,000 fish/ha, yield <500 kg/ha/yr, minimal capital. Semi-intensive: natural productivity enhanced by fertilisation plus supplementary feed, stocking 1,000-10,000 fish/ha, yield 1,000-5,000 kg/ha/yr. Intensive: complete manufactured feed, no natural productivity, stocking >10,000 fish/ha or much higher in tanks, yield >20,000 kg/ha/yr, requires aeration and careful management.
12. Water availability (perennial source); water quality (pH 6.5-8.5, DO >5 mg/L, no pollution); soil suitability (minimum 20-30% clay); topography (gentle slope 0.5-2% for drainage); land tenure and security; proximity to market; access to inputs and technical support; road and infrastructure access.



13. Broodstock selection criteria for female catfish: minimum weight 500 g (ideally 0.5-1.5 kg); age 1-3 years; plump abdomen with no deformities or disease signs; bright eyes and intact fins; confirmed genetic diversity (avoid siblings). Cannulation: inserting a soft flexible catheter into the urogenital opening of a female and gently extracting a small sample of eggs; ripe eggs are round, uniformly large, and amber-coloured; immature eggs are small, irregular, and whitish; the technique avoids sacrificing the female for maturity assessment.
14. Catfish (*Clarias*): 35-45% crude protein. Tilapia (*Oreochromis*): 25-35% crude protein; tilapia can utilise plant proteins more efficiently than catfish, reducing the need for expensive fishmeal. Three protein feed ingredients: fishmeal (high quality, expensive); soyabean meal (good amino acid profile, widely available); groundnut cake (high protein, locally available in Nigeria).
15. Any three: (1) Motile Aeromonas septicaemia (causative agent: *Aeromonas hydrophila*; sign: skin ulcers, haemorrhage, abdominal bloating; treatment: oxytetracycline or florfenicol in feed). (2) Columnaris disease (causative agent: *Flavobacterium columnare*; sign: cotton-wool lesions on skin and gills; treatment: salt bath or oxytetracycline in feed). (3) White spot (causative agent: *Ichthyophthirius multifiliis*; sign: white cysts on skin and gills; treatment: salt bath or formalin dip).

Long-Answer Questions

1. Extensive: no supplementary feed, natural productivity, <1,000 fish/ha, <500 kg/ha/yr; fertilised with organic manure; rice-fish culture in northern Nigeria. Semi-intensive: fertilisation + supplementary feed, 1,000-10,000 fish/ha, 1,000-5,000 kg/ha/yr; most school ponds and small commercial ponds. Intensive: complete manufactured feed, >10,000 fish/ha, >20,000 kg/ha/yr; aeration required; large commercial farms. Earthen pond: most common in Nigeria; constructed by excavation or embankment; components: inlet with screen, monk outlet, spillway, freeboard 0.3-0.5 m, clay embankment. Concrete pond: cleanable, no seepage, intensive systems; circular or rectangular. Hapa: net enclosure in pond for larval nursing. Tarpaulin pond: HDPE-lined, no seepage, relocatable; urban catfish farms. Cage culture: net cages in reservoir or lake; Kainji, Jebba, Shiroro; good water quality from current; risk of flood damage; suitable for tilapia



and catfish. RAS: water recirculated through biofilter (ammonia removal by nitrification), mechanical filter (suspended solids), aeration/oxygenation, UV sterilisation; highest density and production per area; minimal water use; high capital and operating cost; large commercial operators.

2. Site selection criteria: water availability (perennial source, adequate flow); water quality (pH 6.5-8.5, DO >5 mg/L, no pollution or pesticides); soil suitability (minimum 20-30% clay, or lining required); topography (gentle slope 0.5-2% for gravity drainage); land tenure (secure, long-term); proximity to market and inputs; road and electricity access. Most limiting factor in inland Nigeria: dry-season water availability. Pond design: surface area 200-2,000 m²; depth 1.2-1.5 m; embankment top width 0.5-1.0 m; side slopes 1:1.5 to 1:2; freeboard 0.3-0.5 m; inlet at highest point with screen; monk at lowest point. Construction sequence: (1) clear and strip vegetation; (2) survey and stake embankment; (3) excavate and form embankments; (4) compact embankments in layers; (5) install inlet pipe with screen; (6) install monk outlet; (7) construct spillway; (8) allow settling for several weeks; (9) lime pond floor (1-2 t/ha agricultural lime); (10) fill and fertilise before stocking. Infrastructure: feed and tool store; generator; aerators; holding tanks; weighing scale; water quality test kit; farm records (stocking, feeding, water quality, mortality, harvest logs).
3. Broodstock: select females 500 g-1.5 kg, age 1-3 years, plump, no disease; confirm readiness by cannulation (round amber eggs); condition with 35-45% CP feed at 2-3% BW/day, DO >5 mg/L. Hormonal induction: CPE 0.5-0.7 mg/100g or Ovaprim 0.5 mL/kg injected IM at base of dorsal fin; ovulation in 8-12 hours at 27-28 degrees Celsius. Egg stripping: anaesthetise female with clove oil; strip eggs by gentle abdominal massage into dry bowl; dissect testes for sperm; mix thoroughly (dry fertilisation). Incubation: spread eggs on kakaban or in troughs; gentle water flow; hatch 18-24 hrs; remove white dead eggs by siphoning; 60-90% hatching rate. Larval rearing: yolk-sac absorbed in 3-5 days; first feed Artemia nauplii plus finely ground starter feed; 4-8 feeds per day; grade twice weekly to control cannibalism; transfer to nursery ponds at 2-3 weeks; fingerlings 2-5 g in 3-4 weeks. Feeding: catfish 35-45% CP; tilapia 25-35% CP; daily ration 3-5% BW juveniles, 1.5-2.5% large fish; FCR target 1.2-1.8; common ingredients: fishmeal, soyabean meal, groundnut cake, maize, wheat offal. Water quality: temperature 25-30



degrees Celsius; DO >5 mg/L; pH 6.5-8.5; TAN <0.02 mg/L NH₃; test twice weekly; manage by water exchange, aeration, liming, controlled feeding. Disease prevention: biosecurity, good water quality, correct stocking density, quarantine new fish 7-14 days, use disease-free fingerlings. Treatment: Aeromonas (oxytetracycline or florfenicol); Columnaris (salt bath or oxytetracycline); white spot (salt bath or formalin dip); Saprolegnia (KMnO₄ or salt); gill flukes (praziquantel).

Answers to Pilot Questions [Series 3]

Part 3.1: Types of Aquaculture Systems

6. Extensive: no supplementary feed (relies entirely on natural pond productivity from phytoplankton, zooplankton, insects, and detritus); stocking density less than 1,000 fish per hectare; yield less than 500 kg per hectare per year; minimal capital investment. Semi-intensive: combines natural productivity (enhanced by pond fertilisation with organic or inorganic fertiliser) with supplementary pelleted or farm-made feed; stocking density 1,000 to 10,000 fish per hectare; yield 1,000 to 5,000 kg per hectare per year; moderate capital investment. Intensive: complete manufactured feed with no reliance on natural productivity; stocking density 10,000 to 200,000 fish per hectare or higher in tanks; yield 20,000 to 100,000 kg per hectare per year or more; requires aeration, water exchange, and careful daily management; high capital investment.
7. Key structural components of an earthen fish pond: (1) inlet structure (pipe or notch in the embankment that controls water inflow into the pond; fitted with a screen to exclude wild fish, aquatic insects, and large debris); (2) monk outlet structure (vertical stand-pipe made of concrete or PVC with removable boards that control the water level; allows complete pond drainage for harvest or maintenance); (3) overflow spillway (an opening in the embankment set at the maximum desired water level that allows excess water from heavy rain to exit safely without eroding or overtopping the embankment); (4) freeboard (the height of the embankment crest above the maximum water level, typically 0.3-0.5 m,



to prevent wave action and stormwater from overtopping); (5) anti-seepage measures (clay lining, compaction of the embankment, or plastic sheeting laid on the pond floor and walls to reduce seepage in sandy or porous soils).

8. Advantages of cage culture in Nigerian reservoirs: low construction cost compared with earthen ponds (nets and frames only, no excavation); the natural water current through the cage provides continuous oxygenation and removes metabolic waste, reducing the need for aeration; large unused water bodies (Kainji, Jebba, Shiroro reservoirs) are made productive; harvesting is simple (lift net, remove fish). Disadvantages: cages are vulnerable to flooding during reservoir drawdown or storm surges; disease can spread rapidly between adjacent cages through the shared water; theft of fish is difficult to prevent in remote reservoir locations; the farmer cannot control water quality or temperature; cage culture is not suitable for broodstock management or fry and fingerling rearing due to the difficulty of controlling predation and feeding of small fish.
9. RAS (Recirculating Aquaculture System) is a closed or semi-closed system in which water is continuously recirculated through treatment stages (biofilter for ammonia removal, mechanical filter for suspended solids, aeration for oxygen, UV steriliser for pathogen reduction) before being returned to the fish tanks, minimising water use. Advantage for Nigerian aquaculture: RAS allows fish production in urban areas where land and water are scarce; the controlled environment enables year-round production regardless of weather; very high stocking densities and yields are possible; water use is 90-99% less than flow-through systems; biosecurity is excellent. Limitation: the high capital cost of filters, pumps, sensors, and backup systems makes RAS accessible only to well-capitalised operators; electricity dependency is a serious problem in Nigeria where grid supply is unreliable, requiring expensive generators for backup.
10. A hapa is a fine-mesh net enclosure suspended in a pond by floats at the surface and weighted at the bottom; it creates a protected rearing space within the larger pond. In catfish production, hapas are used for nursing very young larvae (day 5 to 21 post-hatch) before transfer to nursery ponds. The hapa protects larvae from predators in the pond, concentrates them for easy feeding and observation, allows daily monitoring of survival and feeding, and can be quickly removed and cleaned. After 2 to 3 weeks in the hapa,



juveniles have grown large enough (about 1 to 2 cm) to be transferred to a larger nursery pond where they continue growing to fingerling size for grow-out stocking.

Part 3.2: Site Selection and Pond Construction

11. Any six criteria: water availability (perennial source of adequate flow; seasonal streams unreliable); water quality (pH 6.5-8.5, DO >5 mg/L, no pesticides or industrial effluent); soil suitability (minimum 20-30% clay to retain water; sandy soils require lining); topography (gentle slope 0.5-2% for gravity drainage; steep slopes are expensive); land tenure and security (secure long-term rights to the land); proximity to market (reduces transport cost and live fish mortality); access to inputs (feed, fingerlings, equipment, technical advice); road and infrastructure access (electricity, communication). Most important factor: water availability during the dry season is the most commonly limiting factor in inland Nigerian aquaculture; without a reliable perennial source the farm cannot operate year-round.
12. Standard dimensions of a catfish grow-out pond: surface area 200 to 2,000 m² (500 to 1,000 m² is most manageable for a single farmer); water depth 1.2 to 1.5 m; embankment top width 0.5 to 1.0 m; embankment side slopes 1:1.5 to 1:2 (horizontal to vertical); freeboard 0.3 to 0.5 m above maximum water level; inlet pipe installed at the highest end of the pond; monk outlet installed at the lowest point of the pond floor to allow complete drainage by gravity.
13. Construction sequence: (1) clear all vegetation, stumps, and debris from the pond area; (2) survey the site and stake the positions of the embankment, inlet, outlet, and spillway; (3) excavate the pond basin to the design depth, using the excavated soil to build the embankments; (4) compact the embankments in successive layers (20-30 cm each) using a roller or hand tamping to eliminate air pockets and ensure strength; (5) install the inlet pipe with an attached fine-mesh screen to exclude wild fish; (6) install the monk outlet structure at the lowest point of the pond floor; (7) construct the overflow spillway in the embankment at the maximum water level elevation; (8) allow the completed embankments to settle and consolidate for several weeks before filling; (9) lime the dry



pond floor with agricultural lime at 1 to 2 tonnes per hectare to disinfect the soil, kill potential pathogens, and raise pH; (10) fill the pond with water and allow natural plankton development for 1 to 2 weeks before stocking fish.

14. Agricultural lime (calcium hydroxide or calcium carbonate) is applied to the dry pond floor before first filling to: disinfect the pond soil by raising pH to 11 or above (killing most bacteria, fungi, and parasites that may be present in the soil from previous flooding or wild fish); neutralise soil acidity (raising the pond pH to the optimal range of 6.5-8.5 for fish production); improve the availability of phosphorus for phytoplankton growth (which is the basis of natural pond productivity in extensive and semi-intensive systems); and harden the embankment surface to reduce erosion when the pond is filled. The standard dose is 1 to 2 tonnes of agricultural lime per hectare of pond floor area.
15. Any five: a dry, secure feed and tool store (with pallets to keep feed bags off the damp floor and prevent mould); an emergency generator for power supply to aerators and pumps during grid outages; aerators (paddle-wheel or diffuser type) for oxygen supplementation in intensive ponds especially at night; fish holding tanks for grading, treating, and live marketing; a platform balance or hanging scale and measuring board for regular fish sampling; a water quality testing kit (thermometer, DO meter or Winkler kit, pH meter or strips, ammonia test kit); farm records (stocking register, daily feeding log, weekly water quality log, mortality record, and harvest/sales record).

Part 3.3: Hatchery Operations and Fingerling Production

1. Broodstock selection criteria for female *Clarias gariepinus*: minimum body weight 500 g (ideally 0.5 to 1.5 kg) to ensure adequate egg mass; age 1 to 3 years for peak reproductive performance; plump, well-rounded abdomen with no deformities or skeletal abnormalities; intact fins, no wounds or ulcers, no external parasites or disease signs; bright, clear eyes indicating good health; confirmed genetic diversity (selected from different families or unrelated lines to prevent inbreeding depression in the hatchery production).



2. Hormonal induction procedure: (1) select a mature female with a soft, swollen abdomen; confirm readiness by cannulation (ripe eggs are round, large, amber-coloured); (2) weigh the female and calculate the hormone dose (for Ovaprim: 0.5 mL per kg body weight; for CPE: 0.5-0.7 mg per 100 g body weight); (3) draw the calculated dose into a syringe; (4) inject the hormone intramuscularly or intraperitoneally at the base of the dorsal fin, advancing the needle at a shallow angle into the muscle; (5) return the female to a holding tank with clean, well-oxygenated water at 27 to 28 degrees Celsius; (6) ovulation occurs 8 to 12 hours after injection; (7) check the female every hour from 8 hours post-injection; when the female shows restless behaviour and eggs can be expressed freely from the vent by gentle pressure, egg stripping is performed.
3. Dry fertilisation method: (1) anaesthetise the ripe female by brief immersion in clove oil solution (50 mg/L) or MS-222 solution; (2) remove the female from the anaesthetic and dry her ventral surface with a clean dry cloth; (3) hold the female over a clean dry bowl and apply gentle but firm massage to the abdomen from anterior to posterior, expressing the eggs into the bowl; (4) sacrifice a ripe male, dissect out both testes, and either macerate the testes or strip sperm by pressing; add sperm to the egg bowl; (5) mix eggs and sperm thoroughly with a dry feather or clean dry finger for 30 to 60 seconds to ensure complete contact between sperm and eggs; (6) add a small amount of clean water to activate the sperm; (7) rinse fertilised eggs gently with clean water and transfer to the incubation troughs or kakaban substrate.
4. Grading is critical because: Clarias larvae show rapid variation in growth rate from as early as day 5 post-hatch; by day 10 some larvae are significantly larger than others; larger larvae are aggressive and will actively attack and consume smaller larvae of their own species (cannibalism) from day 10 onwards. If grading is not performed regularly (at least twice per week), the survival rate of the larval batch drops dramatically due to cannibalism, and the size variation within the batch increases, producing an uneven fingerling batch that stresses smaller fish at all subsequent stages. Grading with progressively larger mesh nets separates larvae into size classes; each size class is reared separately, reducing competition and cannibalism, until all fish converge to a more uniform size by fingerling stage.



5. Transition from Artemia to pelleted feed: (1) from day 5 to day 10-14, the main feed is Artemia nauplii hatched fresh daily, fed ad libitum 4-6 times per day; (2) from day 10, finely ground commercial starter feed (0.2 to 0.5 mm particle size, 50-55% crude protein) is introduced alongside Artemia, with Artemia still the dominant feed; (3) from day 14 to day 21, the proportion of Artemia is gradually reduced while the proportion of formulated starter feed is increased; (4) by day 21 to 28, larvae can be weaned completely off Artemia and onto commercial fry feed (0.5 to 1.0 mm pellet size); Artemia production is discontinued; (5) from day 28 onwards, larvae are fed commercial fingerling feed (1.0 to 2.0 mm pellets) 4 times daily until they reach the target fingerling size (2-5 g) at 3-4 weeks. The transition must be gradual to avoid feed refusal, growth check, and increased cannibalism.

Part 3.4: Feeding, Water Quality, and Disease Management

1. Catfish (*Clarias gariepinus*): requires 35 to 45 per cent crude protein for optimal growth; it is omnivorous with a preference for animal protein and requires a higher proportion of fish or animal meal in the diet. Tilapia (*Oreochromis niloticus*): requires 25 to 35 per cent crude protein; it is an omnivore that can utilise plant proteins (soyabean meal, groundnut cake, leaf meal) efficiently due to its longer, more active digestive system and ability to digest algae and plant cell walls; the lower protein requirement of tilapia makes it cheaper to feed and explains why tilapia production is economically competitive. The difference is fundamentally due to the different protein metabolism and digestive enzyme complement of the two species.
2. Total fish biomass = 500 fish x 200 g = 100,000 g = 100 kg. Daily feed at 3% body weight = $\frac{3}{100} \times 100 \text{ kg} = 3 \text{ kg}$ of feed per day.
3. Any five water quality management practices: (1) water exchange (replace 10-30% of pond water per day by opening the inlet and partly opening the monk outlet; removes accumulated ammonia, nitrite, and carbon dioxide); (2) aeration (operate paddle-wheel or diffuser aerators especially between midnight and dawn when DO is lowest due to respiration; emergency aeration when fish are observed gulping at the surface); (3) liming



(apply agricultural lime at 50-100 kg per hectare when pH falls below 6.5; raises pH and restores buffering capacity of pond water); (4) controlled feeding (never exceed the fish's appetite; feed at fixed times and observe for uneaten feed; uneaten feed decays and increases ammonia and BOD); (5) stocking density management (reduce stocking density if chronic low DO or high ammonia are detected; thin the pond by partial harvesting or transfer to an additional pond).

4. Any three with causative agent, sign, and treatment: (1) Motile Aeromonas septicaemia: causative agent *Aeromonas hydrophila* (gram-negative bacterium); main sign skin ulcers, haemorrhaging at fin bases and body surface, abdominal bloating with bloody ascitic fluid; treatment oxytetracycline at 75 mg/kg body weight per day in feed for 10 days, or florfenicol at 10 mg/kg BW/day for 10 days. (2) Columnaris disease: causative agent *Flavobacterium columnare* (gram-negative rod); main sign yellow-white to grey cotton-wool-like lesions on the skin, fins, and gills; treatment salt bath (0.5-1% sodium chloride for 10-30 minutes) or oxytetracycline in feed for 10 days. (3) White spot (*Ichthyophthirius multifiliis*): causative agent is a protozoan ectoparasite; main sign small white raised cysts covering the skin, fins, and gills causing respiratory distress and lethargy; treatment salt bath (1-2% for 15 minutes) or formalin dip (25 mL per 100 litres for 30-60 minutes).
5. Any five disease prevention strategies: (1) biosecurity: prevent introduction of pathogens by screening all water inflows, disinfecting equipment between ponds, and not allowing wild fish into the system; (2) use disease-free fingerlings from certified hatcheries with a documented health history; (3) quarantine all new fish in a separate facility for 7 to 14 days and observe for disease signs before introducing them to the main farm system; (4) maintain optimal water quality at all times (DO >5 mg/L, pH 6.5-8.5, TAN <0.02 mg/L NH₃); most bacterial and fungal diseases are secondary to stress caused by poor water quality; (5) control stocking density to prevent overcrowding, which increases stress, physical injuries, and pathogen transmission; (6) disinfect ponds between crops using lime (1-2 t/ha) and sun-drying the pond floor for at least 2 weeks before refilling; (7) observe fish daily for abnormal behaviour (surface gulping, reduced feeding, isolation, abnormal swimming posture) as early warning signs.



References and Attributions [Series 3]

Textual References (Books and External Sources)

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

Figures, Plates, Tables, and Boxes

1. Figure 3.1: Earthen catfish pond cross-section Attribution: AI generated. Suggested OER search string: "earthen fish pond cross-section diagram inlet monk outlet levee freeboard OER".
2. Figure 3.2: Catfish hatchery operations flowchart Attribution: AI generated. Suggested OER search string: "catfish hatchery operations flowchart broodstock hormone spawning fingerling OER".
3. Table 3.1: Catfish pond design parameters Attribution: AI generated. Suggested OER search string: "catfish pond design parameters dimensions grow-out school pond OER table".
4. Table 3.2: Water quality parameters for catfish and tilapia Attribution: AI generated. Suggested OER search string: "water quality parameters catfish tilapia pond optimal critical limits OER table".



5. Box 3.1: Disease prevention checklist Attribution: AI generated. Suggested OER search string: "catfish farm disease prevention checklist biosecurity water quality Nigeria OER box".



Course code: AGE 308

Course title: Fish Farming and Management

Series 4: Management, Production, and Business Strategies in Aquaculture

- **Part 4.1: Grow-Out Management and Harvesting**
 - Sub Part 4.1.1: Stocking, monitoring, and pond management
 - Sub Part 4.1.2: Harvesting methods and timing
 - Sub Part 4.1.3: Fish preservation and post-harvest handling
- **Part 4.2: Production Planning and Record Keeping**
 - Sub Part 4.2.1: Planning a production cycle
 - Sub Part 4.2.2: Farm records and performance indicators
 - Sub Part 4.2.3: Sampling, grading, and population estimation
- **Part 4.3: Aquaculture Business Management**
 - Sub Part 4.3.1: Capital requirements and farm budgeting
 - Sub Part 4.3.2: Cost analysis, pricing, and profitability
 - Sub Part 4.3.3: Marketing strategies for farmed fish in Nigeria
- **Part 4.4: Fishing Gears, Methods, and Environmental Considerations**
 - Sub Part 4.4.1: Types and characteristics of common fishing gears
 - Sub Part 4.4.2: Fishing methods and their selectivity
 - Sub Part 4.4.3: Environmental and social impacts of fishing



Introduction

Running a fish farm as a viable enterprise requires more than biological knowledge; it demands disciplined operational management, systematic record keeping, financial planning, and effective marketing. This Series moves from the pond-level practices of grow-out management and harvesting through to the business and economic dimensions of aquaculture. We also cover the types of fishing gears and methods used in capture fisheries, which a fisheries management professional must understand alongside aquaculture practices.

We begin with grow-out pond management and harvesting, cover production planning and record keeping, address the business fundamentals of budgeting, cost analysis, and marketing, and conclude with a survey of common fishing gears and their environmental impacts. The business content of this Series is directly applicable to establishing and operating a catfish farm at any scale, from school pond to commercial enterprise.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 4.1** describe the management of a grow-out catfish or tilapia pond from stocking to harvest (Linked to Part 4.1),
- **SLO 4.2** describe harvesting methods and post-harvest handling of farmed fish (Linked to Part 4.1),
- **SLO 4.3** plan a fish production cycle and design a farm record-keeping system (Linked to Part 4.2),
- **SLO 4.4** describe sampling and population estimation methods for fish ponds (Linked to Part 4.2),
- **SLO 4.5** prepare a farm budget, conduct a cost-benefit analysis, and calculate break-even production for a catfish farm (Linked to Part 4.3),



- **SLO 4.6** describe marketing strategies for farmed fish in Nigeria and identify major market channels (Linked to Part 4.3), and
- **SLO 4.7** describe the major types of fishing gears and methods used in Nigerian fisheries and explain their environmental impacts (Linked to Part 4.4).

4.1 Grow-Out Management and Harvesting

4.1.1 Stocking, monitoring, and pond management

Grow-out management begins with stocking. Before stocking, the pond should be limed and filled 7 to 14 days in advance to allow plankton development (a "bloom" of green algae and zooplankton, visible as green-coloured water, indicates the pond is ready). Fingerlings (2 to 5 g) are acclimatised to the pond temperature by floating the transport container on the pond surface for 15 to 20 minutes before release. Recommended stocking densities for catfish in earthen ponds: 1 to 3 fish per m² for semi-intensive systems; 5 to 10 fish per m² for intensive earthen ponds; up to 50 to 100 fish per m² in concrete tanks with aeration and daily water exchange. For tilapia monosex culture: 2 to 4 fish per m² in earthen ponds.

Routine pond monitoring includes: daily feeding (observe fish response to feed within 30 minutes; reduce ration if fish do not consume all feed; increase ration as biomass grows); daily observation (watch for abnormal behaviour: surface gulping indicates low DO; lethargy and skin lesions indicate disease; sudden mortality indicates acute toxicity); bi-weekly or monthly sampling (net a random sample of 30 to 50 fish, weigh individually or as a batch, measure a subset for length; calculate mean weight, condition factor K, and adjust feed ration accordingly); and water quality monitoring twice weekly (early morning DO and pH measurements are most critical). Pond water level is maintained by adjusting the inlet and outlet.

Fill in the blank: Before stocking fingerlings, the pond is filled 7 to 14 days in advance to develop a _____ of green algae and zooplankton; fingerlings are acclimatised to pond temperature by floating the transport container on the pond surface for 15 to 20 minutes.

4.1.2 Harvesting methods and timing



Catfish are harvested when they reach market weight (500 g to 1.5 kg for most Nigerian markets; the preferred weight varies by region and market type). The decision to harvest is based on: market price (harvest when price is high; avoid harvesting during price troughs such as Christmas when supply floods the market); fish weight (sample and calculate mean weight; harvest when at least 80 per cent of fish have reached the target weight); feed conversion (if FCR is rising above 2.5, fish are no longer converting feed efficiently and the pond is past its optimal harvest point); and cash flow needs of the farm.

Harvesting methods: partial harvesting (using a seine net to selectively remove the largest fish while returning smaller ones to the pond; used to extend the production cycle and maintain cash flow without draining the pond); complete harvesting by draining (the pond is completely drained through the monk outlet over 12 to 24 hours; fish are collected in a harvest basin or net installed at the monk; the most thorough method, recovering nearly all fish); and direct netting without draining (using a drag seine or cast net repeatedly until most fish are removed; less effective in large ponds). After draining, the pond floor is sun-dried and limed before the next production cycle.

Fill in the blank: The decision to harvest catfish is based on market price, mean fish weight, and feed conversion ratio; if FCR rises above _____, the fish are no longer converting feed efficiently and the pond should be harvested.



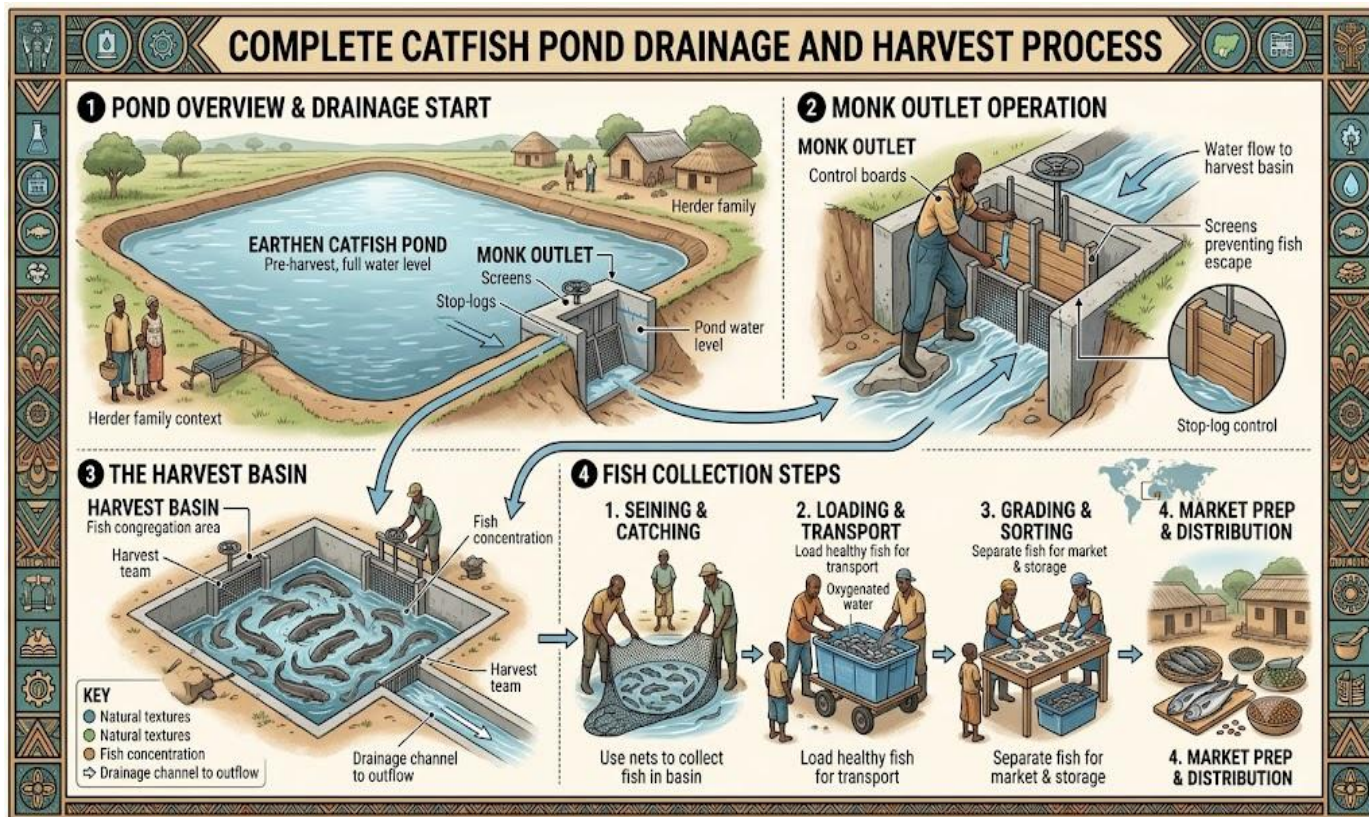


Figure 4.1: Diagram showing complete pond drainage harvest with monk outlet, harvest basin, and fish collection

4.1.3 Fish preservation and post-harvest handling

Catfish has a short shelf life without preservation; at ambient temperatures (28 to 35 degrees Celsius in Nigeria) an ungutted catfish deteriorates within 6 to 12 hours of death. Post-harvest handling steps: fish are removed from the harvest basin and placed in containers with crushed ice at a 1:1 ratio (ice to fish by weight) for live-fish transport or immediate sale; for smoking, fish are gutted, cleaned, and placed on smoking racks above a firewood or charcoal fire for 4 to 8 hours to reduce moisture content below 15 per cent; for freezing, gutted fish are blast-frozen at minus 18 to minus 30 degrees Celsius and stored in a cold room; for frying (point-of-sale processing), fish are cut into portions, marinated, and deep-fried.

Smoking is the dominant preservation method for catfish in Nigeria because it requires no electricity, is widely practised, and produces a product (grilled or smoked catfish, "eja gbigbe" in Yoruba) that commands a premium price and has a shelf life of 2 to 4 weeks at ambient



temperatures. The Chorkor smoker (an improved clay oven with stackable trays) improves fuel efficiency and smoking throughput compared with traditional methods. Icing (use of ice or chilled water) maintains live-fish quality for transport to urban markets; air transport to distant cities requires polystyrene boxes with ice. Post-harvest losses for catfish in Nigeria are estimated at 10 to 20 per cent due to inadequate cold chains and rough handling during transport.

Fill in the blank: _____ is the dominant post-harvest preservation method for catfish in Nigeria, requiring no electricity; it produces smoked catfish with a shelf life of 2 to 4 weeks at ambient temperatures.

Pilot questions 4.1

- Describe the preparation of a pond before stocking and explain the acclimatisation procedure for fingerlings.
- State the recommended stocking density for catfish in semi-intensive earthen ponds and intensive concrete tanks.
- Describe three methods of harvesting catfish from a grow-out pond.
- Explain how a farmer decides when to harvest catfish.
- Describe the steps in post-harvest handling of catfish intended for the smoking market.

4.2 Production Planning and Record Keeping

4.2.1 Planning a production cycle

A production cycle (from stocking fingerlings to harvest) for catfish in Nigeria typically lasts 4 to 6 months. Planning a cycle begins with setting the target: the farmer decides the target market weight (e.g. 800 g), stocking density (e.g. 3 fish/m² in a 500 m² pond = 1,500 fish), anticipated mortality rate (10 to 15 per cent is typical; plan for 85 to 90 per cent survival), and target harvest weight per pond (e.g. 1,500 fish x 85% survival x 800 g = 1,020 kg = 1.02 tonnes). Feed



requirement is estimated: if target production is 1.02 tonnes and FCR target is 1.5, total feed needed = $1.02 \times 1.5 = 1.53$ tonnes of feed.

Production planning also covers: scheduling stocking dates to ensure harvest falls in a period of good market price (avoid Christmas and Easter peak supply periods; target lean months of July to October); sourcing fingerlings in advance (book fingerlings from the hatchery 4 to 6 weeks before stocking to ensure size and quantity); staggered stocking of multiple ponds (offset stocking dates by 4 to 6 weeks to provide continuous cash flow from staggered harvests rather than one large harvest per year); and contingency planning (maintain a disease treatment budget, arrange a backup water source, identify an alternative buyer in case the primary buyer fails to show at harvest time).

Fill in the blank: Feed requirement for a production cycle = target production (kg) x _____; if target production is 1.02 tonnes and FCR is 1.5, then 1.53 tonnes of feed are needed.

4.2.2 Farm records and performance indicators

Systematic farm records are essential for managing a catfish farm scientifically. The minimum set of records includes: stocking record (date, pond, species, number stocked, mean weight, source of fingerlings, cost); daily feeding log (date, pond, feed quantity kg, feed type, fish response); bi-weekly sampling record (date, pond, number sampled, mean weight, mean length, condition factor K, estimated total biomass, adjusted feed ration); water quality log (date, pond, DO mg/L, pH, temperature, ammonia if available, corrective actions taken); mortality log (date, pond, number of dead fish, estimated weight, probable cause); and harvest record (date, pond, total weight harvested, number harvested, mean weight, disposal: sold, smoked, frozen).

Key performance indicators (KPIs) derived from records: survival rate (number harvested / number stocked x 100%); specific growth rate ($SGR = (\ln \text{ final weight} - \ln \text{ initial weight}) / \text{days} \times 100$; expressed as per cent body weight per day); feed conversion ratio (total feed used / total weight gain); production per pond (kg); production per m²; return on investment (ROI).

Comparing KPIs against targets and against previous cycles enables the farmer to identify management problems (declining SGR suggests nutritional or health problems; rising FCR suggests overfeeding or water quality deterioration) and improve performance systematically.



Fill in the blank: Specific growth rate (SGR) = (ln final weight minus ln initial weight) / days x 100; it expresses fish growth as _____ body weight gained per day.

<u>Record Type</u>	<u>Key Data Fields</u>
Stocking Record	Date stocked, pond ID, number of fingerlings, average weight, source of fingerlings
Feeding Record	Date, feed type, feed quantity, feeding frequency, pond ID
Water Quality Record	Date, pond ID, temperature, pH, dissolved oxygen, ammonia levels
Health/Disease Record	Date, pond ID, observed symptoms, treatments applied, mortality count
Harvest Record	Date harvested, pond ID, number harvested, average weight, total yield, sales destination
Financial Record	Date, expenses (feed, fingerlings, labor, maintenance), income (sales), profit/loss
Mortality Record	Date, pond ID, number of deaths, suspected cause, corrective action taken

Table 4.1: Catfish farm record-keeping system showing the minimum required records and their key data fields

4.2.3 Sampling, grading, and population estimation

Regular sampling of fish from the pond is necessary to monitor growth, adjust feed rations, and detect health problems early. Sampling method: drag a seine net across the pond to capture a random sample of 30 to 50 fish; weigh the batch and divide by the number of fish to get the mean weight; measure total length of a subset (10 to 20 fish) with a measuring board; calculate condition factor K for each measured fish; compare mean weight with the expected weight for that week in the production plan. If mean weight is below target, investigate feed quality, feed quantity, water quality, and disease. The feed ration is then recalculated based on the updated estimated total biomass (mean weight x estimated number surviving).



Population estimation: the farmer estimates the number of fish in the pond by counting mortalities removed daily and subtracting from the original stocking number; this gives a running estimate of the surviving population. Total biomass estimate = estimated number surviving x current mean weight from sampling. Grading (sorting by size into two or three size classes) is done during sampling to reduce competition and ensure uniform growth; fish of significantly different sizes fed together result in large fish dominating the feeding area and small fish falling further behind. In tilapia ponds, grading also helps remove any mixed-sex fish that escaped sex reversal, since females (which grow slower) can be identified and removed.

Fill in the blank: Total biomass estimate in a grow-out pond = estimated number of _____ fish x current mean weight from sampling; this estimate is used to calculate the correct daily feed ration.

Pilot questions 4.2

- Plan a catfish production cycle for a 1,000 m² pond stocked at 2 fish per m² with a target harvest weight of 700 g and expected survival of 85 per cent.
- State five types of farm records that a catfish farmer must maintain and state what each records.
- Explain why staggered stocking of multiple ponds improves the business performance of a fish farm.
- Describe the sampling procedure for a grow-out catfish pond and explain how the results are used.
- Define SGR and FCR and explain how each is used to monitor fish farm performance.

4.3 Aquaculture Business Management

4.3.1 Capital requirements and farm budgeting

Establishing a catfish farm requires capital for fixed assets and working capital. Fixed (capital) costs are one-time investments that last multiple production cycles: land acquisition or lease;



pond construction (earthen pond: approximately NGN 150,000 to 500,000 per 500 m² depending on soil conditions; concrete tank: NGN 500,000 to 2,000,000); borehole or water supply infrastructure; electricity connection or generator; feed store; aerators and pumps; and initial equipment (nets, weighing scale, water quality kit). Working (operational) costs recur in every production cycle: fingerlings; feed (typically 60 to 70 per cent of total production cost in intensive catfish farming); medications and chemicals; labour; electricity or fuel; transport; and packaging.

A farm budget projects income and expenditure for one or more production cycles. It consists of: production cost (sum of all variable costs per cycle); fixed cost allocation per cycle (annual fixed costs divided by number of cycles per year); total cost per cycle; projected revenue (harvest weight kg x expected selling price per kg); gross margin (revenue minus variable costs); net profit or loss (gross margin minus fixed cost allocation). A simple budget for a 500 m² earthen catfish pond might show: 1,500 fingerlings at NGN 30 each = NGN 45,000; feed 1.2 tonnes at NGN 400,000/tonne = NGN 480,000; other variable costs NGN 75,000; total variable cost NGN 600,000; expected harvest 850 kg at NGN 900/kg = NGN 765,000; gross margin NGN 165,000 per cycle.

Fill in the blank: Feed typically accounts for _____ to 70 per cent of total production cost in intensive catfish farming in Nigeria, making feed efficiency (FCR) the most important driver of profitability.

4.3.2 Cost analysis, pricing, and profitability

The cost of production per kilogram of fish = total production cost / harvest weight. If total production cost (fixed + variable) for a cycle is NGN 700,000 and harvest weight is 850 kg, the production cost = NGN 824/kg. The selling price must exceed the cost of production per kg for the farm to be profitable. Break-even price = total cost / harvest weight (kg). Break-even production (kg) = total fixed cost / (selling price - variable cost per kg). Sensitivity analysis shows how profit changes when key variables (fingerling price, feed price, fish selling price, survival rate) change; it identifies which variables have the greatest impact on profitability.



Profitability in Nigerian catfish farming is squeezed by rising feed costs (imported fishmeal and soyabean meal), unreliable electricity (increasing fuel costs for pumps and aerators), and price competition from imported frozen fish. Strategies to improve profitability: reduce FCR through better feed management (prevent overfeeding; use quality feed); reduce mortality through biosecurity and water quality management; produce in the off-season when prices are higher; add value by selling smoked or fried catfish rather than live fish; integrate feed production (farm-made feed from locally available ingredients reduces feed cost); and form cooperatives for collective purchasing of inputs at volume discounts.

Fill in the blank: The break-even _____ per kg = total production cost divided by harvest weight; the selling price must exceed this for the farm to be profitable.

4.3.3 Marketing strategies for farmed fish in Nigeria

The main market channels for farmed catfish in Nigeria are: live fish sales at the farm gate (highest price, minimal post-harvest loss, but dependent on buyer coming to the farm; popular with restaurants, hotels, and caterers); live fish sales at urban markets (catfish transported in water containers by motorcycle or pickup truck to fish markets; second-highest price; risk of mortality during transport); smoked catfish (sold by the piece or kg at markets, roadside stalls, and supermarkets; longer shelf life enables wider distribution); frozen catfish (blast-frozen and sold to restaurants, hotels, and export-oriented buyers; requires cold chain infrastructure); and wholesale (selling the entire harvest to a single trader at a discounted bulk price for quick turnover and immediate cash; reduces price but eliminates marketing burden).

Marketing strategies: building a regular customer base (relationships with restaurants, caterers, institutional buyers such as schools and hospitals reduce the need to find new buyers at each harvest); social media and mobile phone marketing (WhatsApp groups, Facebook, Instagram are widely used by Nigerian fish farmers to announce harvest availability and prices to buyers); value addition (smoking, portioning, and packaging increase the price per kg and open up supermarket channels); timing of harvest to exploit seasonal price peaks (prices are highest in the lean production months of July to October and at key occasions such as Eid and end-of-year; avoid January to March when prices are lowest); and collective marketing through cooperatives.



Fill in the blank: Live fish sold at the _____ gate achieves the highest price per kg for catfish because it eliminates middlemen and post-harvest processing costs.

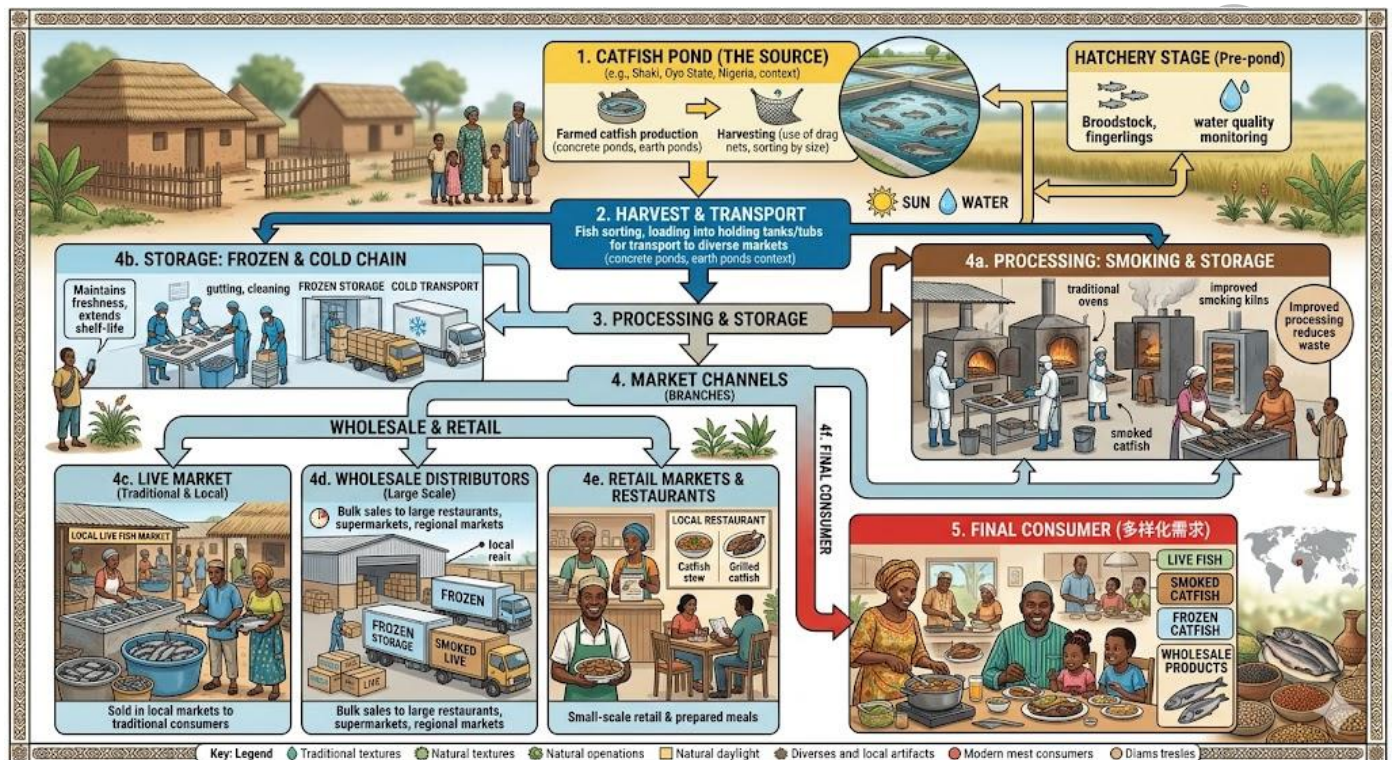


Figure 4.2: Diagram of the major market channels for farmed catfish in Nigeria from farm to consumer

Pilot questions 4.3

1. Distinguish between fixed costs and working costs in a catfish farm and give two examples of each.
2. Using the example in the text, calculate the break-even price per kg for a catfish farm with total production cost of NGN 700,000 and harvest weight of 850 kg.
3. State five strategies a catfish farmer can use to improve farm profitability.
4. Name four market channels for farmed catfish in Nigeria and explain the advantage of each.
5. Explain why timing of catfish harvest is important for farm profitability in Nigeria.



4.4 Fishing Gears, Methods, and Environmental Considerations

4.4.1 Types and characteristics of common fishing gears

Fishing gears are the tools and devices used to capture fish from their natural environments. They are classified as: nets (gill nets, seine nets, cast nets, trawl nets, lift nets); traps (fish traps, pots, baskets); lines (hook-and-line, long lines, hand lines); and other gears (spears, harpoons, bow-and-arrow, fish fences, electric fishing, poisons). Gill nets are vertical walls of netting suspended in the water; fish swim into the mesh and are caught by the gills or entangled; they are the most widely used artisanal gear in Nigerian inland and coastal waters. Mesh size is the key design parameter: larger mesh targets larger fish and improves selectivity, reducing by-catch of juvenile fish.

Seine nets are large encircling nets hauled toward the shore or a central boat by two teams pulling from opposite ends; they enclose a large volume of water and capture most fish in the area without selectivity by size. The beach seine is operated from shore; the purse seine is operated by two boats at sea and can be closed at the bottom (pursed) to capture pelagic schooling fish like bonga and sardinellas. The cast net is a circular net thrown by hand to cover fish in shallow water; commonly used in rivers and ponds in Nigeria. Trawl nets are cone-shaped nets towed by a powered vessel along the bottom (bottom trawl for demersal fish) or in midwater; they are used by industrial vessels in the Nigerian EEZ.

Fill in the blank: Gill nets are vertical walls of netting suspended in water; fish are caught when they swim into the mesh and are caught by the _____; mesh size is the key design parameter determining which sizes of fish are caught.

<u>Gear Type</u>	<u>Environment</u>	<u>Target Species</u>	<u>Selectivity</u>	<u>Management Status</u>
Gill nets	Rivers, lakes, coastal waters	Tilapia, catfish, croaker	Moderate selectivity (mesh size dependent)	Regulated mesh sizes; risk of juvenile capture if misused



Cast nets	Rivers, lagoons, shallow waters	Small tilapia, juvenile fish	Low selectivity	Common artisanal gear; minimal regulation
Longlines	Rivers, lakes, marine waters	Catfish, croaker, large predatory fish	High selectivity (hook size and bait)	Licensed use; sustainable if controlled
Traps (basket/pot traps)	Rivers, floodplains, lagoons	Catfish, tilapia, crustaceans	High selectivity (species-specific)	Traditional gear; widely accepted, low ecological impact
Seine nets (beach seines)	Coastal waters, lagoons	Sardines, bonga shad	Low selectivity; captures mixed species	Restricted in some areas due to bycatch concerns
Trawls	Marine waters (industrial fisheries)	Shrimp, croaker, demersal fish	Low selectivity; high bycatch risk	Strictly licensed; monitored for sustainability
Hook and line	Rivers, lakes, coastal waters	Catfish, tilapia, perch	Very high selectivity	Traditional, sustainable; minimal regulation needed

Table 4.2: Common fishing gears used in Nigeria with their characteristics and target species

4.4.2 Fishing methods and their selectivity

Fishing methods determine the size, species, and abundance of fish captured and the collateral damage to non-target species and habitats. Selective methods target specific species or size classes with minimal by-catch: gill nets of the correct mesh size; hook-and-line (only bait-taking fish of appropriate size are caught); fish traps with species-specific bait. Non-selective methods capture all fish in the area regardless of species or size: seine nets; poisons (rotenone, bleaching powder, or other toxic substances poured into a stream to stun or kill all fish; illegal but practiced in some Nigerian communities); and explosives (dynamite fishing; destroys all fish and habitat in the blast area; illegal).



Mesh size regulation is the most important tool for improving the selectivity of nets: minimum legal mesh sizes prevent capture of juvenile fish before they have spawned at least once. In Nigeria, the Fisheries Act prohibits nets with a mesh size of less than 50 mm in the inland waters. Fine-mesh (mosquito net) fishing, often used illegally to harvest juvenile and larval fish, is one of the most destructive practices in Nigerian inland fisheries as it removes entire year classes of fish and prevents stock replenishment. Other destructive methods prohibited under the Fisheries Act include electric fishing, use of toxic chemicals, and use of explosives.

Fill in the blank: Minimum legal _____ size regulations prevent the capture of juvenile fish before they have reproduced at least once; the Fisheries Act prohibits nets with a mesh size less than 50 mm in Nigerian inland waters.

4.4.3 Environmental and social impacts of fishing

Fishing has significant environmental impacts beyond the direct removal of target fish. Overfishing (harvesting above the maximum sustainable yield) depletes fish populations, reduces their average size and age at maturity, and can lead to stock collapse if sustained. By-catch (non-target species caught incidentally) causes mortality of juvenile fish, undersized individuals, marine mammals, sea turtles, and seabirds; bottom trawling physically destroys benthic habitats (coral reefs, seagrass beds, and soft-bottom communities that serve as nursery areas and feeding grounds for many species). Ghost fishing (abandoned or lost fishing gear continuing to capture and kill fish and other organisms) is a growing problem in Nigerian coastal and inland fisheries.

Social impacts of fisheries include: employment and livelihood dependency of coastal and riverine communities; conflicts between artisanal fishers and industrial trawlers in the EEZ and inshore waters; gender dimensions (women dominate fish processing and trading while men dominate active fishing); and food insecurity when stocks decline. Aquaculture is sometimes presented as the solution to overfishing of wild stocks, but it also has environmental impacts: nutrient loading from uneaten feed and faeces in cage culture; introduction of exotic species and genetically modified organisms; use of wild fish (fishmeal and fish oil) in aquaculture feeds; and risk of disease transfer from farmed to wild fish. Balancing food production goals with



environmental sustainability is the central challenge of modern fisheries and aquaculture management.

Fill in the blank: _____ fishing occurs when abandoned or lost fishing gear continues to capture and kill fish and other organisms unintentionally; it is a growing problem in Nigerian coastal and inland waters.

Pilot questions 4.4

1. Name four types of fishing gears and describe how each captures fish.
2. Distinguish between selective and non-selective fishing methods and give one example of each.
3. Explain why fine-mesh (mosquito net) fishing is considered the most destructive method in Nigerian inland fisheries.
4. Describe three environmental impacts of industrial trawl fishing in the Nigerian EEZ.
5. Explain the social dimensions of fisheries in Nigeria, covering gender, employment, and conflict.

Series Summary

This Series covered the management, business, and gear dimensions of aquaculture and fisheries. On the production side, we described grow-out pond management from stocking (plankton bloom preparation, fingerling acclimatisation, recommended densities) through routine monitoring (daily feeding and observation, bi-weekly sampling, water quality testing) to harvesting (partial harvest, complete drainage, direct netting) and post-harvest handling (icing, smoking, freezing). We covered production planning (target-setting, feed estimation, staggered stocking), record keeping (stocking, feeding, sampling, water quality, mortality, and harvest records), and performance indicators (survival rate, SGR, FCR, production per m², ROI).



On the business side, we distinguished fixed from working costs, constructed a simple farm budget, calculated cost of production per kg, break-even price, and profitability, and described strategies to improve farm financial performance. We identified the major market channels for farmed catfish in Nigeria (live farm gate, urban markets, smoked, frozen, wholesale) and marketing strategies (regular buyer relationships, social media, value addition, harvest timing, cooperatives). Finally, we described the major fishing gears (gill nets, seines, cast nets, trawls, traps, lines), the selectivity of fishing methods, and the environmental and social impacts of fishing. By completing this Series, you should be able to achieve all seven Series Learning Outcomes (SLO 4.1 to SLO 4.7).

Glossary of Terms

1. **Beach seine:** a large encircling net operated from the shore by two teams pulling from opposite ends; used in coastal and riverine artisanal fisheries.
2. **Break-even price:** the minimum selling price per kg at which a catfish farm recovers its total production cost; calculated as total production cost divided by harvest weight.
3. **By-catch:** non-target organisms (wrong species, wrong size) caught incidentally during fishing operations; a major cause of marine biodiversity loss.
4. **Cast net:** a circular net thrown by hand to cover fish in shallow water and then retrieved; widely used in rivers and ponds in Nigeria.
5. **Chorkor smoker:** an improved clay or brick smoking kiln with stackable wire trays; more fuel-efficient and higher-throughput than traditional drum or clay pot smokers.
6. **Complete harvesting:** draining the pond fully through the monk outlet and collecting all fish in a harvest basin; the most thorough harvesting method.
7. **Condition factor (K):** $K = 100W/L^3$; a measure of fish plumpness used in routine sampling to monitor nutritional status and adjust management.



8. **Feed conversion ratio (FCR):** kg of feed used per kg of fish produced; FCR of 1.2-1.8 is the target for well-managed catfish; FCR above 2.5 indicates overfeeding or poor management.
9. **Fixed (capital) costs:** one-time investment costs in a fish farm (land, pond construction, equipment) that last multiple production cycles and do not vary with production volume.
10. **Ghost fishing:** the continued capture and killing of fish by abandoned or lost fishing gear; a growing problem in Nigerian coastal and inland fisheries.
11. **Gill net:** a vertical wall of netting suspended in the water; fish are caught when they swim into the mesh and are caught by the gills or entangled; mesh size determines fish size selectivity.
12. **Gross margin:** revenue minus variable (working) costs; a measure of the profitability of a fish farm before fixed cost allocation.
13. **Key performance indicators (KPIs):** quantitative measures of fish farm performance including survival rate, SGR, FCR, production per m², and return on investment.
14. **Long line:** a fishing method using a main line to which many shorter branch lines (snoods) with baited hooks are attached; used to target demersal fish over large areas.
15. **Monk outlet:** the water level control and drainage structure in an earthen pond; boards are removed at harvest to drain the pond completely.
16. **Partial harvesting:** using a seine net to selectively remove the largest fish from a pond while returning smaller fish to continue growing; used to maintain cash flow without draining the pond.
17. **Plankton bloom:** the development of a visible green coloration in newly filled pond water caused by rapid growth of phytoplankton; indicates the pond has natural food available for fingerlings.
18. **Production cycle:** the period from stocking fingerlings to harvest; typically 4 to 6 months for catfish in Nigeria.



19. **Purse seine:** a large net operated by two boats that encircles a school of pelagic fish and can be closed at the bottom to prevent escape; used for bonga and sardinella in Nigerian coastal waters.
20. **Return on investment (ROI):** net profit divided by total capital invested, expressed as a percentage; a measure of the overall financial performance of a fish farm.
21. **Selectivity:** the tendency of a fishing gear or method to capture specific sizes or species of fish while allowing others to escape; high selectivity reduces by-catch.
22. **Specific growth rate (SGR):** $(\ln \text{ final weight} - \ln \text{ initial weight}) / \text{days} \times 100$; expresses fish growth as per cent body weight gained per day; a standard measure of growth performance.
23. **Staggered stocking:** offsetting the stocking dates of multiple ponds by 4 to 6 weeks so that harvests occur at intervals throughout the year, providing continuous cash flow.
24. **Trawl net:** a cone-shaped net towed by a powered vessel along the bottom (bottom trawl) or in midwater; used by industrial vessels in the Nigerian EEZ; low selectivity.
25. **Working (operational) costs:** costs that recur in every production cycle (fingerlings, feed, medication, labour, electricity, transport); also called variable costs.

Concept Check Questions [Series 4]

Objective Questions

1. Before stocking fingerlings, the pond should be filled 7 to 14 days in advance to develop a plankton _____ of green algae and zooplankton. (Linked to SLO 4.1)
2. If FCR rises above _____, the fish are no longer converting feed efficiently and the pond should be harvested promptly. (Linked to SLO 4.1)
3. Specific growth rate (SGR) = $(\ln \text{ final weight} - \ln \text{ initial weight}) / \text{days} \times 100$; it expresses fish growth as _____ body weight gained per day. (Linked to SLO 4.3)



4. Feed typically accounts for 60 to _____ per cent of total production cost in intensive catfish farming in Nigeria. (Linked to SLO 4.5)
5. Gill nets are vertical walls of netting; fish are caught when they swim into the mesh and are caught by the _____; mesh size determines fish size selectivity. (Linked to SLO 4.7)

Short-Answer Questions

- Describe three methods of harvesting catfish from a grow-out pond. (Linked to SLO 4.2)
- State five types of farm records a catfish farmer must maintain. (Linked to SLO 4.3)
- Distinguish between fixed and working costs in a fish farm and give two examples of each. (Linked to SLO 4.5)
- Name four market channels for farmed catfish in Nigeria and state one advantage of each. (Linked to SLO 4.6)
- Name three destructive fishing methods prohibited under the Nigerian Fisheries Act and explain why each is destructive. (Linked to SLO 4.7)

Long-Answer Questions

1. Describe the complete management of a catfish grow-out cycle from pond preparation and stocking through routine monitoring, harvesting, and post-harvest handling. (Linked to SLOs 4.1, 4.2)
2. Describe how a catfish farmer plans a production cycle, maintains farm records, monitors performance indicators (SGR, FCR, survival rate), and estimates pond population and biomass. (Linked to SLOs 4.3, 4.4)
3. Describe the business management of a catfish farm covering capital requirements, budgeting, cost of production, break-even analysis, profitability improvement strategies, and marketing channels, and describe the major fishing gears, their selectivity, and their environmental and social impacts. (Linked to SLOs 4.5, 4.6, 4.7)



Answers to Concept Check Questions [Series 4]

Objective Questions

6. Bloom.
7. 2.5.
8. Per cent.
9. 70.
10. Gills.

Short-Answer Questions

11. Partial harvesting: seine net used to selectively remove the largest fish while smaller fish are returned to continue growing; no pond draining; maintains production. Complete harvesting by draining: pond is drained through the monk outlet; fish accumulate in the harvest basin; most thorough method recovering nearly all fish. Direct netting without draining: repeated drag seine or cast net passes in the pond to remove most fish; less effective than draining in large ponds.
12. Any five: stocking record (date, number, weight, source, cost); daily feeding log (date, pond, feed quantity, fish response); bi-weekly sampling record (number sampled, mean weight, mean length, K factor, adjusted feed ration); water quality log (DO, pH, temperature, ammonia, corrective actions); mortality log (date, number dead, weight, probable cause); harvest record (total weight, number, mean weight, sale details).
13. Fixed costs: one-time investments that last multiple cycles, do not vary with production volume; examples: pond construction, borehole or water supply infrastructure. Working costs: recur in every production cycle, vary with production volume; examples: fingerlings, feed.
14. Live farm gate sales (highest price, minimal post-harvest loss); live urban market sales (good price, wider reach); smoked catfish (long shelf life, no cold chain needed, premium



price per kg); frozen catfish (cold chain required, suitable for hotels and restaurants, enables export).

15. Fine-mesh (mosquito net) fishing: removes all fish including larvae and juveniles, depleting entire year classes; poison fishing (rotenone or bleaching powder): kills all fish and other aquatic organisms in the water body, destroys biodiversity; explosive (dynamite) fishing: kills all fish in the blast radius and physically destroys the benthic habitat, preventing recovery.

Long-Answer Questions

1. Pond preparation: lime dry pond floor (1-2 t/ha), fill 7-14 days before stocking, develop plankton bloom (green water); apply organic fertiliser if semi-intensive. Stocking: acclimatise fingerlings (float container 15-20 min); recommended density catfish semi-intensive earthen pond 1-3 fish/m²; intensive concrete tank 50-100/m²; tilapia monosex 2-4/m². Routine monitoring: daily feeding (observe consumption within 30 min; adjust ration); daily observation (surface gulping = low DO; lethargy/lesions = disease; sudden mortality = acute toxicity); bi-weekly sampling (30-50 fish, mean weight, length subset, K factor, adjust feed ration; recalculate biomass); twice-weekly water quality (early morning DO and pH most critical). Harvesting: partial (seine net, remove largest, return smaller, no pond drain; maintains cash flow); complete drainage (drain through monk 12-24 hrs, collect in harvest basin; most thorough); direct netting (multiple seine or cast net passes without draining; less effective). Decision to harvest: market price high; mean weight 80% at target; FCR above 2.5 means efficiency declining. Post-harvest: icing (1:1 ice to fish, live transport and immediate sale); smoking (gut, clean, smoke 4-8 hrs on Chorkor smoker to <15% moisture; smoked catfish "eja gbigbe" preferred product; 2-4 week shelf life); freezing (blast-freeze at -18 to -30 degrees Celsius for hotel/restaurant/export); farm gate frying (portion, marinate, deep-fry for point-of-sale).
2. Production cycle planning: set target market weight, stocking density, expected survival (85-90%), target harvest weight = number stocked x survival% x target weight; feed requirement = target production x FCR. Schedule stocking for harvest in high-price



months (July-October); book fingerlings 4-6 weeks in advance; stagger multiple ponds by 4-6 weeks for continuous cash flow; contingency budget for disease treatment and backup water source. Farm records: stocking (date, number, weight, source, cost); daily feeding (quantity, type, response); bi-weekly sampling (mean weight, length, K, biomass estimate, feed ration adjustment); water quality (DO, pH, temperature, ammonia, corrective actions); mortality (date, number, weight, cause); harvest (weight, number, mean weight, revenue). Performance indicators: survival rate = number harvested / number stocked x 100%; SGR = (ln final weight - ln initial weight) / days x 100 (% BW/day); FCR = total feed / total weight gain; production per m²; ROI. Population estimation: initial stock minus cumulative mortality count = estimated surviving population; total biomass = estimated surviving population x current mean weight from sampling; this biomass estimate is used to recalculate daily feed ration (ration = biomass x feeding rate %). Grading: sort by size with grading nets to reduce size variation and competition; in tilapia ponds, removes slower-growing females that escaped sex reversal.

3. Capital requirements: fixed costs (land, pond construction NGN 150,000-500,000 per 500 m² earthen or NGN 500,000-2,000,000 concrete, borehole, generator, aerators, equipment); working costs (fingerlings, feed 60-70% of production cost, medications, labour, electricity/fuel, transport, packaging). Farm budget: total variable cost + fixed cost allocation per cycle; revenue = harvest weight x selling price; gross margin = revenue - variable cost; net profit = gross margin - fixed cost allocation. Cost of production per kg = total production cost / harvest weight; break-even price = total cost / harvest weight; break-even production = total fixed cost / (price - variable cost per kg). Example: total cost NGN 700,000; harvest 850 kg; production cost per kg = NGN 824; selling price must exceed NGN 824 to profit. Profitability strategies: reduce FCR (better feed management, avoid overfeeding); reduce mortality (biosecurity, water quality); off-season production (July-October high prices); value addition (smoked, fried catfish premium); farm-made feed from local ingredients; cooperatives for bulk input purchasing. Market channels: live farm gate (highest price, no transport cost, dependent on buyer visiting); live urban market (second-highest price, risk of transport mortality); smoked catfish (long shelf life, market stalls and supermarkets, no cold chain); frozen (cold chain required, hotels, restaurants, export); wholesale (bulk at discount, immediate



cash, no marketing effort). Marketing strategies: regular buyer relationships; WhatsApp/social media announcement of harvest; value addition and packaging; harvest timing to price peaks; cooperative collective sales. Fishing gears: gill nets (vertical walls, mesh-size selective, artisanal rivers and coast); seine nets (encircling, low selectivity, beach seine and purse seine); cast nets (hand-thrown, circular, shallow water); trawl nets (cone-shaped, towed by vessel, bottom trawl for demersal or midwater pelagic, industrial EEZ); traps (species-specific bait, highly selective); long lines (baited hooks, targets specific biting species). Selectivity: selective methods (gill nets correct mesh, hook-and-line, traps); non-selective methods (seines, poisons, explosives). Destructive and prohibited: fine-mesh <50 mm (removes juveniles and larvae, depletes year classes); poison fishing (kills all organisms); explosive/dynamite fishing (kills all fish, destroys habitat). Environmental impacts: overfishing (above MSY, stock depletion, smaller mean size); by-catch (juvenile mortality, marine mammals, sea turtles); bottom trawling (destroys coral, seagrass, benthic communities); ghost fishing. Social impacts: employment and livelihood dependency; artisanal vs industrial conflicts; gender (women in processing and trading, men in active fishing); food insecurity as stocks decline. Aquaculture impacts: nutrient loading from cages; exotic species introduction; fishmeal dependency; disease transfer risk.

Answers to Pilot Questions [Series 4]

Part 4.1: Grow-Out Management and Harvesting

6. Pond preparation before stocking: (1) lime the dry pond floor with agricultural lime at 1-2 tonnes per hectare and allow to dry; (2) fill the pond with water from the inlet; (3) apply organic fertiliser (poultry litter or cow dung at 500-1,000 kg per hectare) or inorganic fertiliser to stimulate phytoplankton growth; (4) wait 7 to 14 days until the water has developed a green coloration (plankton bloom), indicating that natural food organisms are available for fingerlings. Fingerling acclimatisation: transport containers (plastic bags or buckets) are floated on the pond surface for 15 to 20 minutes to allow the water



temperature inside to gradually equilibrate with the pond temperature; this prevents thermal shock, which can cause sudden death from osmotic stress and immune suppression. After equilibration, the container is tilted to allow fingerlings to swim out into the pond.

7. Recommended stocking density for catfish in semi-intensive earthen ponds: 1 to 3 fish per m² (the lower density relies more on natural pond productivity; the higher density requires more supplementary feed and better water management). Recommended stocking density in intensive concrete tanks with aeration and daily water exchange: 50 to 100 fish per m²; at this density the fish are entirely dependent on manufactured feed and the water quality management (aeration, water exchange, monitoring) must be intensive and consistent to prevent ammonia accumulation and oxygen depletion.
8. Three harvesting methods: (1) partial harvesting using a seine net: a drag seine is pulled across the pond to capture the largest fish; fish larger than the minimum market size are sorted out and sold, while smaller fish are returned to the pond to continue growing; this method can be repeated every 4 to 6 weeks without disturbing the entire pond and provides regular cash flow. (2) Complete harvesting by draining: the monk outlet boards are removed one by one over 12 to 24 hours to gradually drain the pond; fish concentrate in the harvest basin installed in front of the monk as the water level falls; workers collect the fish from the basin; this method recovers approximately 95 to 99 per cent of the fish in the pond. (3) Direct netting without draining: multiple passes with a drag seine or repeated cast net throws are used to remove fish from the pond without draining; suitable for a rapid harvest when draining is not possible, but less thorough than complete drainage, leaving 20 to 40 per cent of fish uncollected.
9. A farmer decides to harvest catfish based on four main indicators: (1) market price (harvest when the farm-gate or market price for live or smoked catfish is at a seasonal high; avoid harvesting during periods of price depression such as after Christmas when many farms harvest simultaneously and flood the market); (2) fish weight (sample the pond bi-weekly and calculate the mean weight; harvest when at least 80 per cent of sampled fish have reached the target market weight for the customer type, e.g. 700-900 g for restaurant buyers); (3) feed conversion ratio (if FCR calculated from feed records and biomass estimates is rising above 2.5 kg feed per kg fish, the fish are past their optimal



growth phase and further feeding is uneconomical; harvest before further feed investment without adequate return); (4) cash flow need (if the farm urgently needs cash for the next cycle, operational costs, or other obligations, harvest is triggered regardless of other factors).

10. Post-harvest handling for smoked catfish: (1) transfer harvested fish quickly from the harvest basin to containers of water or ice to prevent stress-related quality loss; (2) gut (eviscerate) each fish by making a ventral incision and removing the intestines and other organs; (3) wash the gutted fish thoroughly in clean water to remove blood, mucus, and gut contents; (4) marinate if desired (salt, pepper, seasonings) or proceed directly to smoking; (5) arrange fish on the wire racks of the Chorkor smoker or traditional smoking kiln; (6) smoke at a moderate temperature for 4 to 8 hours, turning fish and repositioning trays periodically to ensure even smoking; the objective is to reduce moisture content below 15 per cent; (7) allow smoked fish to cool on the racks; (8) grade by size, weigh, package in paper or perforated polyethylene bags, and label for market; (9) store in a cool, dry, ventilated place until sold; shelf life is 2 to 4 weeks at ambient temperatures.

Part 4.2: Production Planning and Record Keeping

11. Production cycle plan for a 1,000 m² pond at 2 fish/m²: number stocked = $1,000 \times 2 = 2,000$ fish. Target harvest weight per fish = 700 g = 0.7 kg. Expected survival = 85%. Expected number harvested = $2,000 \times 0.85 = 1,700$ fish. Expected total harvest weight = $1,700 \times 0.7 \text{ kg} = 1,190 \text{ kg} = 1.19$ tonnes. Feed requirement (at FCR 1.5) = $1.19 \times 1.5 = 1.785$ tonnes = approximately 1,800 kg of feed. Production duration: 4 to 6 months depending on initial fingerling size and water temperature. Fingerlings should be booked 4 to 6 weeks before stocking date.
12. Any five farm records with what each records: (1) stocking record (date of stocking; pond identification; species; number of fingerlings stocked; mean weight at stocking; source of fingerlings; cost per fingerling and total fingerling cost); (2) daily feeding log (date; pond; quantity of feed applied in kg; feed type and brand; observed fish feeding response; any abnormalities noted); (3) bi-weekly sampling record (date; pond; number of fish



sampled; total weight of sample batch; mean weight; total length measurements; calculated condition factor K; estimated total biomass; revised daily feed ration); (4) water quality log (date and time; pond; dissolved oxygen in mg/L; pH; water temperature; ammonia if measured; corrective action taken such as water exchange or liming); (5) mortality log (date; pond; number of dead fish counted and removed; estimated total weight of dead fish; probable cause of mortality; treatment applied); (6) harvest record (date; pond; total weight harvested in kg; estimated number of fish harvested; mean weight at harvest; disposal: sold live, smoked, frozen; revenue received).

13. Staggered stocking of multiple ponds by 4 to 6 weeks improves farm business performance in three ways: (1) continuous cash flow: instead of one large harvest per year, the farm generates revenue at regular intervals (every 4 to 6 weeks if multiple ponds are staggered across the 4 to 6 month production cycle), enabling the farmer to meet operational expenses, service debt, and reinvest in the business without cash-flow gaps; (2) market spread: smaller, more frequent harvests are easier to sell at good prices because they do not flood the market simultaneously; a single large harvest from all ponds at once may force the farmer to sell at a discounted bulk price; (3) risk distribution: if one pond experiences disease, poor water quality, or other failure, the other ponds stocked at different times continue producing; the risk is not concentrated in a single cohort.
14. Sampling procedure: use a seine net or cast net to capture a random sample of 30 to 50 fish from the grow-out pond; try to sample from different areas of the pond (inlet end, middle, and outlet end) to avoid size-biased sampling. Weigh the entire sample batch on a hanging or platform scale and divide by the number of fish to get the mean weight. Measure total length from the tip of the snout to the end of the caudal fin for a subset of 10 to 20 fish using a measuring board; calculate condition factor $K = 100W/L^3$ for each measured fish and average. Return fish to the pond promptly after sampling to minimise stress. How results are used: compare mean weight with the production plan's expected weight for that week; if below target, investigate feed quality, feed quantity, water quality, and disease status; recalculate total biomass (estimated surviving number x mean weight) and adjust the daily feed ration accordingly (daily ration = total biomass x feeding rate %).



15. $\text{SGR (specific growth rate)} = (\ln \text{ final weight} - \ln \text{ initial weight}) / \text{number of days} \times 100$; it expresses growth as per cent body weight gained per day. It is used to compare growth performance between ponds, between production cycles, and against published benchmarks for the species; a declining SGR within a cycle may indicate nutritional deficiency, disease, overcrowding, or deteriorating water quality. $\text{FCR (feed conversion ratio)} = \text{total feed used (kg)} / \text{total weight gained (kg)}$; lower FCR means more efficient use of feed and lower feed cost per kg of fish produced. FCR is used to monitor feed management efficiency: an FCR above the target (1.2-1.8 for catfish) indicates overfeeding, feed wastage, poor feed quality, or growth retardation from disease or water quality problems. Together, SGR and FCR are the two most important production efficiency indicators for a catfish farm manager.

Part 4.3: Aquaculture Business Management

1. Fixed (capital) costs: one-time investment costs that last multiple production cycles and do not vary with the volume of fish produced; examples: (1) pond construction cost (NGN 150,000-500,000 for a 500 m² earthen pond; this cost is incurred once and spreads over many production cycles); (2) borehole or water supply infrastructure (drilling, casing, pump installation; one-time capital investment). Working (operational) costs: costs that recur in every production cycle and are directly proportional to production volume; examples: (1) fingerling purchase (cost repeats for every new stocking cycle); (2) feed cost (purchased every cycle in proportion to the number and size of fish being grown).
2. Break-even price per kg = total production cost / harvest weight = NGN 700,000 / 850 kg = NGN 824 per kg. This means the farmer must sell catfish at a price above NGN 824 per kg to make a profit. If the current market price for live catfish at the farm gate is NGN 900 per kg, the profit per kg = NGN 900 - NGN 824 = NGN 76 per kg; total profit = 850 kg x NGN 76 = NGN 64,600 per production cycle.
3. Any five strategies: (1) reduce FCR through strict feed management (feed exactly at the calculated ration; observe fish response and reduce ration if feed is left uneaten; avoid



overfeeding which increases feed cost and ammonia loading); (2) reduce fingerling and grow-out mortality through biosecurity (quarantine new fish; disinfect ponds between cycles; maintain optimal water quality); (3) produce in the off-season months (July to October) when market supply is lower and prices are higher; (4) add value by selling smoked or fried catfish rather than live fish to obtain higher price per kg and reach supermarket and processed food channels; (5) produce farm-made feed from locally available ingredients (soyabean meal, groundnut cake, maize, blood meal) to reduce dependence on expensive commercial feed; (6) join a cooperative or farmer group to negotiate bulk purchase of inputs at lower prices and achieve better market access.

4. Four market channels with advantages: (1) live farm gate sales (buyers come to the farm; highest price per kg because no middleman or transport cost; preferred by restaurants, caterers, and household buyers who want live fresh catfish); (2) live urban market sales (catfish transported in aerated water containers or polythene bags to city fish markets; reaches a larger buyer pool; second-highest price though transport mortality risk exists); (3) smoked catfish market (processed at farm or nearby; long shelf life of 2-4 weeks eliminates the urgency of immediate sale; reaches market stalls, roadside sellers, and supermarkets; no cold chain required); (4) wholesale to traders (entire harvest sold in bulk to a single trader at a discounted price; advantage is immediate cash settlement, no marketing effort, and elimination of all post-harvest handling; suitable when the farmer needs quick turnover).
5. Timing of catfish harvest is important for farm profitability in Nigeria because the market price for catfish varies significantly by season and occasion: prices are highest during the lean months of July to September when most farms have not yet harvested (low supply, high demand); prices are lowest in January to March and in the weeks immediately after Christmas and New Year when many farms harvest simultaneously and flood the market. An otherwise profitable farm can make a loss by harvesting at the wrong time. For example, if the break-even price is NGN 824/kg and the farmer harvests in January when market price is NGN 750/kg, every kilogram sold incurs a loss of NGN 74. Conversely, harvesting in August when prices are NGN 1,100/kg turns the same production cost into a substantial profit. Strategic harvest timing is therefore one of the most powerful tools



available to the catfish farmer for improving financial returns without changing production inputs.

Part 4.4: Fishing Gears, Methods, and Environmental Considerations

1. Any four gears with description of capture mechanism: (1) Gill net: a rectangular panel of netting suspended vertically in the water, held at the surface by floats and at the bottom by weights or a lead line; fish swimming into the net are caught when their head passes through the mesh but their body cannot follow, and the mesh catches them by the gill covers, or they become entangled in the netting; widely used in Nigerian inland and coastal artisanal fisheries. (2) Cast net (throw net): a circular net with small lead weights around the perimeter; thrown by hand to spread over a circular area of water above fish in shallow water; as the net sinks, the lead weights pull the perimeter down, enclosing fish inside; retrieved by pulling a line attached to the centre; used in rivers, lagoons, and fish ponds in Nigeria. (3) Trawl net: a cone-shaped net with a wide mouth, a narrowing body, and a closed end (codend); towed by a powered vessel through the water; the mouth is kept open by otter boards or floats and weights; fish are swept into the codend as the net is towed; bottom trawls target demersal fish on the Nigerian continental shelf; used by industrial vessels in the EEZ. (4) Fish trap or pot: a rigid or semi-rigid structure with a funnel entrance that fish can enter but cannot easily exit; baited with specific attractants for the target species; placed in the water and retrieved after 12 to 48 hours; highly selective for target species.
2. Selective methods target specific species or size classes with minimal by-catch of non-target organisms: example: gill net with the correct legal mesh size (only fish whose body width matches the mesh opening are retained; smaller fish pass through; larger fish are not gilled). Non-selective methods capture all fish present regardless of species, size, or reproductive status: example: seine net or beach seine (encircles and retains all fish in the swept area including juveniles, non-target species, and spawning adults).
3. Fine-mesh (mosquito net) fishing is considered the most destructive method in Nigerian inland fisheries for three reasons: (1) it captures fish of all sizes, including eggs, larvae,



and juvenile fish that have not yet reached reproductive maturity; this removes entire year classes from the population before they have had any opportunity to reproduce and contribute to stock replenishment; (2) the mesh is so small (0.5 to 5 mm) that virtually no fish can escape, removing a much higher proportion of the standing stock than any size-selective gear; and (3) it targets the nursery areas (shallow flooded areas, river margins, and lake littoral zones) where fish larvae and juveniles concentrate, destroying the most critical habitat for stock recruitment. A single night's fishing with mosquito nets in a river section can remove the majority of the larval and juvenile fish present, affecting stock abundance for the next 1 to 3 years.

4. Three environmental impacts of industrial trawl fishing in the Nigerian EEZ: (1) overfishing of demersal stocks: industrial trawlers target bottom-dwelling species (croakers, snappers, groupers) at high intensity; catch rates of many demersal species on the Nigerian continental shelf have declined significantly since the 1970s as a result of sustained effort above MSY levels, indicating stock depletion; (2) by-catch mortality: trawl nets are largely non-selective; juvenile fish, non-target species (including sea turtles and marine mammals), undersized individuals, and commercially valuable shrimps are caught incidentally and mostly die before being discarded; by-catch in Nigerian shrimp trawl fisheries can exceed the weight of the target shrimp catch by a factor of 3 to 5; (3) physical destruction of benthic habitats: the footrope and otter boards of bottom trawls plough through the seabed, destroying corals, sponges, seagrass beds, and soft-bottom community structures that serve as nursery areas, feeding grounds, and refugia for many commercial and non-commercial species.
5. Social dimensions of Nigerian fisheries: Employment and livelihood: fisheries directly employ over 8 million Nigerians in catching, processing, and trading fish; coastal and riverine communities are entirely dependent on fisheries for their livelihood; for many households, fishing or fish trading is the only source of cash income; a decline in fish stocks directly translates into poverty and food insecurity in these communities. Gender: there is a strong gender division of labour in Nigerian fisheries; men dominate active fishing (going to sea, operating boats and nets, diving); women dominate post-harvest activities (fish processing, smoking, drying, and trading); women fish traders (known locally as "mama fish" or "iya eja") are important economic actors who provide capital,



storage, and marketing for fishing households; women traders are often the primary decision-makers on fish pricing and distribution. Conflict: competition between artisanal fishers and industrial trawlers is a chronic conflict in Nigerian waters; industrial trawlers operating illegally inside the 3 to 12 nautical mile inshore exclusion zone reserved for artisanal fishers damage artisanal gear (cutting nets, running over boats) and deplete inshore stocks; inter-community conflict between fishing communities from different states or ethnic groups over fishing rights in shared water bodies (particularly Lake Chad and the Niger-Benue floodplain) is also common.

References and Attributions [Series 4]

Textual References (Books and External Sources)

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2. FAO (Food and Agriculture Organization of the United Nations). (2022). The state of world fisheries and aquaculture 2022. FAO.
3. Okafor-Yarwood, I. (2019). Illegal, unreported and unregulated fishing, and the complexities of the sustainable development goals (SDGs) for countries in the Gulf of Guinea. *Marine Policy*, 99, 414-422.
4. Njoku, D. C., & Ezike, S. C. (2014). Economic analysis of catfish production in Imo State, Nigeria. *Journal of Agriculture and Sustainability*, 6(1), 39-50.
5. FAO (Food and Agriculture Organization of the United Nations). (2025). Guidelines for sustainable agriculture. FAO.

Figures, Plates, Tables, and Boxes



1. Figure 4.1: Catfish pond drainage harvest diagram Attribution: AI generated. Suggested OER search string: "catfish pond harvest drainage monk outlet harvest basin Nigeria OER".
2. Table 4.1: Catfish farm record-keeping system Attribution: AI generated. Suggested OER search string: "catfish farm record keeping system stocking feeding sampling water quality OER table".
3. Figure 4.2: Market channels for farmed catfish in Nigeria Attribution: AI generated. Suggested OER search string: "catfish market channels Nigeria live smoked frozen wholesale OER diagram".
4. Table 4.2: Common fishing gears in Nigeria Attribution: AI generated. Suggested OER search string: "fishing gears Nigeria gill net seine net trawl trap characteristics OER table".



Course code: AGE 308

Course title: Fish Farming and Management

Course credit load: 2 Units

Series 5: Research, Innovation, and Environmental Sustainability in Fisheries

- **Part 5.1: Research Methods in Fisheries and Aquaculture**
 - Sub Part 5.1.1: Types of fisheries and aquaculture research
 - Sub Part 5.1.2: Scientific methods and data collection
 - Sub Part 5.1.3: Statistical methods and data presentation
- **Part 5.2: Innovation and Technology in Aquaculture**
 - Sub Part 5.2.1: Genetic improvement and selective breeding
 - Sub Part 5.2.2: Feed technology and alternative protein sources
 - Sub Part 5.2.3: Digital and precision aquaculture technologies
- **Part 5.3: Environmental Sustainability in Fisheries and Aquaculture**
 - Sub Part 5.3.1: Aquatic habitat and ecosystem health
 - Sub Part 5.3.2: Aquaculture and the environment
 - Sub Part 5.3.3: Climate change and Nigerian fisheries
- **Part 5.4: Professional Skills and the Fisheries Graduate**
 - Sub Part 5.4.1: Information retrieval and use of scientific literature
 - Sub Part 5.4.2: Oral and written presentation of scientific findings



- Sub Part 5.4.3: Career pathways in fisheries and aquaculture

Introduction

Fisheries and aquaculture are dynamic sciences whose practices are continuously shaped by research discoveries, technological innovations, environmental pressures, and policy decisions. The student who graduates with only current knowledge, without the ability to access and evaluate new research, is professionally equipped only for today's challenges and not for those of tomorrow. This final Series equips students with the research and analytical skills that underpin professional practice in fisheries and aquaculture, covers the major innovations transforming the sector, addresses the environmental sustainability challenges that are the defining issue of our time, and maps the career pathways available to fisheries graduates in Nigeria.

We cover the types of fisheries research and scientific methods, statistical tools for analysing and presenting data, genetic improvement and selective breeding of farmed fish, alternative feed ingredients, digital aquaculture technologies, the health of aquatic habitats, the environmental footprint of aquaculture, the impact of climate change on Nigerian fisheries, and the professional skills of information retrieval, scientific presentation, and career planning. Together these topics complete the course and prepare students for professional practice.

Series Learning Outcomes

Upon completing this Series, you should be able to:

- **SLO 5.1** describe the types of fisheries and aquaculture research and the scientific methods used to conduct them (Linked to Part 5.1),
- **SLO 5.2** select appropriate statistical methods for fisheries and aquaculture data and present results in tables and graphs (Linked to Part 5.1),



- **SLO 5.3** describe the major innovations in genetic improvement, feed technology, and digital aquaculture relevant to Nigerian fish farming (Linked to Part 5.2),
- **SLO 5.4** explain the importance of aquatic habitat health and describe the key indicators of aquatic ecosystem degradation (Linked to Part 5.3),
- **SLO 5.5** explain the environmental impacts of aquaculture and describe strategies to reduce the environmental footprint of fish farming (Linked to Part 5.3),
- **SLO 5.6** describe the observed and projected impacts of climate change on Nigerian fisheries and aquaculture and evaluate adaptation strategies (Linked to Part 5.3), and
- **SLO 5.7** retrieve and evaluate scientific literature, present fisheries research findings effectively, and identify career pathways in fisheries and aquaculture (Linked to Part 5.4).

5.1 Research Methods in Fisheries and Aquaculture

5.1.1 Types of fisheries and aquaculture research

Fisheries and aquaculture research falls into four broad categories. Basic (fundamental) research investigates biological principles without immediate applied objectives: examples include studies of fish population genetics, reproductive physiology, and ecosystem dynamics. Applied research addresses specific practical problems: examples include trials of new feed formulations, disease treatment protocols, and pond construction materials. Adaptive research tests the applicability and performance of technologies already proven elsewhere under local conditions: an example is testing an improved catfish breed developed in Europe for growth performance under Nigerian conditions. Action research involves farmers directly: production problems are identified and solutions tested on farms with farmer participation, making the findings immediately relevant and adoption more likely.

Other important research types in fisheries include stock assessment research (estimating the abundance, growth, and mortality of wild fish populations to support catch limit decisions), environmental monitoring research (tracking changes in water quality, habitat condition, and biodiversity over time), and socioeconomic research (studying the livelihoods, gender dynamics, market systems, and policy impacts of fishing communities). In Nigeria, NIFFR, NIOMR,



university departments of aquaculture and fisheries, and IITA conduct fisheries research; international collaboration with FAO, WorldFish, and the African Development Bank provides additional funding and expertise.

Fill in the blank: _____ research tests the applicability of technologies already proven elsewhere under local Nigerian conditions, such as evaluating a foreign catfish breed for growth performance in Nigerian ponds.

5.1.2 Scientific methods and data collection

The scientific method in fisheries research follows a systematic sequence: observation and problem identification (what is happening that needs investigation?); literature review (what is already known?); hypothesis formulation (a testable statement of the expected relationship between variables); experimental design (planning how to test the hypothesis while controlling for confounding variables); data collection (systematic, accurate recording of measurements); data analysis (statistical testing of whether the data support or refute the hypothesis); interpretation and conclusion (what do the results mean, and how do they compare with existing knowledge?); and dissemination (reporting results in a thesis, journal article, or conference presentation for peer review).

Data collection methods in fisheries and aquaculture include: experimental pond or tank trials (comparing treatment groups under controlled conditions, e.g. different feed formulations tested in replicated tanks); field surveys (sampling fish populations from rivers, lakes, or coastal waters using standardised gear and effort); biological sampling (measuring length, weight, age from otoliths, and reproductive state of sampled fish); water quality measurement (using calibrated instruments for DO, pH, temperature, ammonia, turbidity); questionnaire surveys (collecting socioeconomic data from fishers, traders, and consumers); and remote sensing and acoustic methods (sonar, echo-sounding, and satellite imagery for mapping fish habitats and estimating stock biomass).

Fill in the blank: The scientific method follows the sequence: observation, literature review, hypothesis formulation, experimental _____, data collection, analysis, interpretation, and dissemination of results.



5.1.3 Statistical methods and data presentation

Descriptive statistics summarise a dataset: mean (average), median (middle value), standard deviation (spread around the mean), and standard error (precision of the mean estimate). These are reported in tables and graphs and are the minimum statistical description for any fisheries dataset. Inferential statistics test whether differences observed between treatment groups are statistically significant (not due to chance): the t-test compares the means of two groups; analysis of variance (ANOVA) compares the means of three or more groups; regression analysis quantifies the relationship between two variables (for example, the relationship between fish weight and fish length). In aquaculture trials, ANOVA is the most commonly used test because most experiments compare three or more treatment groups (for example, three different protein levels in catfish feed).

Data presentation follows conventions: tables present exact values (mean weight, standard deviation, sample size) and are used when precise numbers are important; bar charts compare means across treatment groups and are used when the main comparison is between categories; line graphs show trends over time and are used for growth curves, temperature profiles, and time-series data; scatter plots show the relationship between two continuous variables (for example, body weight against length); and pie charts show proportional composition (for example, the composition of a fish diet in per cent dry matter). All graphs and tables must have a clear title, labelled axes with units, and a legend where relevant.

Fill in the blank: Analysis of variance (_____) is the most commonly used inferential statistical test in aquaculture feed trials because it compares the means of three or more treatment groups simultaneously.



Figure 5.1: Example of a well-formatted bar chart comparing the growth rates of catfish fed three different protein levels

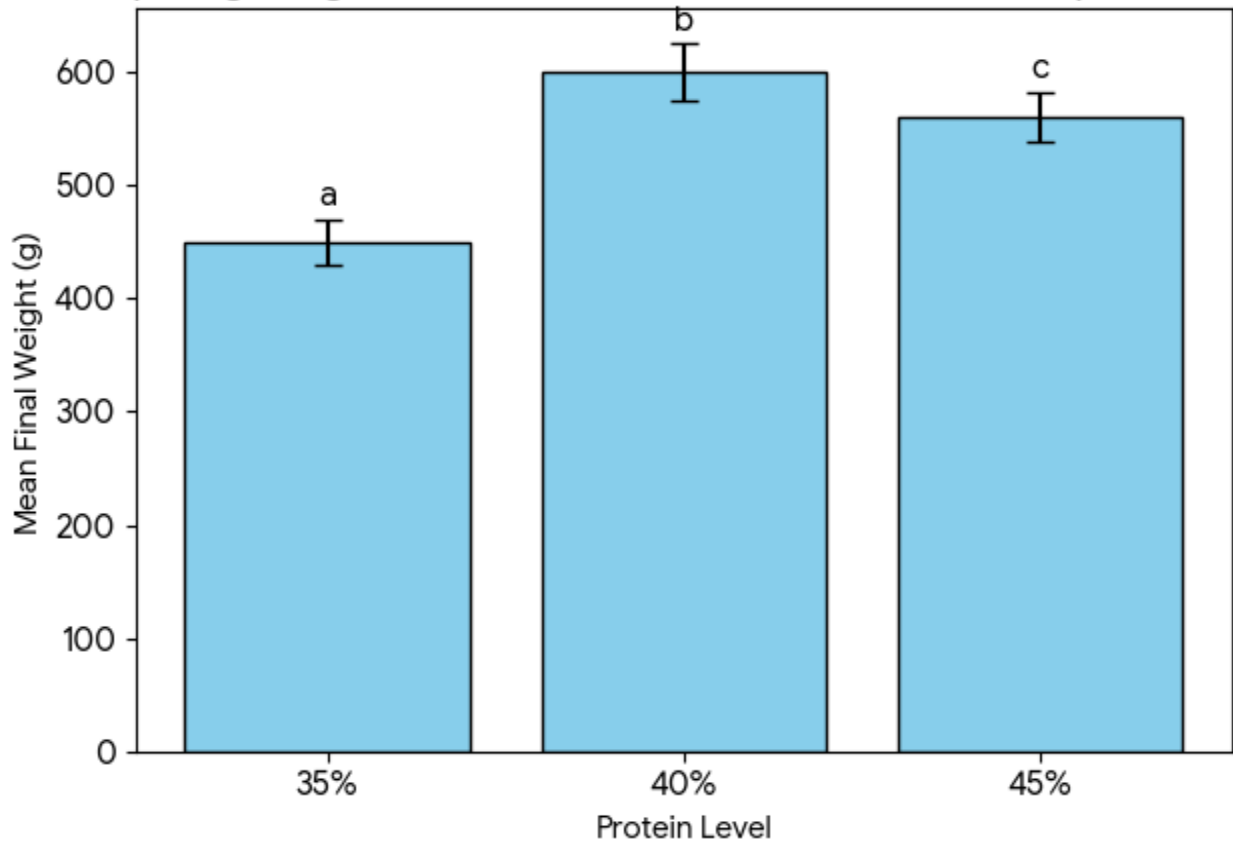


Figure 5.1: Example of a well-formatted bar chart comparing the growth rates of catfish fed three different protein levels

Pilot questions 5.1

- Distinguish between basic, applied, adaptive, and action research in fisheries and give one Nigerian example of each.
- Describe the steps of the scientific method as applied to an aquaculture feeding trial.
- Explain when a t-test and when an ANOVA should be used in analysing aquaculture data.
- State the difference between a bar chart and a line graph and explain when each is appropriate in fisheries research.
- Explain what standard deviation and standard error represent in a fisheries dataset.



5.2 Innovation and Technology in Aquaculture

5.2.1 Genetic improvement and selective breeding

Selective breeding of farmed fish applies the same principles as plant and animal breeding: superior individuals (fast-growing, disease-resistant, feed-efficient) are selected as parents, their offspring are evaluated, and the cycle is repeated over multiple generations. The Nigerian catfish (*Clarias gariepinus*) has been the subject of selective breeding programmes at NIFFR and several universities; improved strains showing 20 to 40 per cent higher growth rates than unselected local strains have been produced. Hybridisation between *Clarias gariepinus* and *Heterobranchus longifilis* produces the "heteroclarias" or "hatchery catfish" hybrid, which is fast-growing and shows some heterosis for growth and survival, though fertility may be reduced.

Genetic improvement through molecular tools is advancing rapidly. Marker-assisted selection uses DNA markers associated with genes for disease resistance, growth, or feed efficiency to identify and select superior individuals without waiting for phenotypic expression. Genomic selection uses the combined information from thousands of DNA markers across the genome to predict the breeding value of individuals. Chromosome manipulation (production of triploid fish using pressure or thermal shock; produces sterile fish that divert energy from reproduction to growth) and sex reversal (monosex culture of male tilapia using methyltestosterone) are applied genetic technologies already used in Nigerian aquaculture. These approaches collectively define modern aquaculture genetics and are central to the next generation of productivity improvements.

Fill in the blank: The "heteroclarias" hybrid is produced by crossing *Clarias gariepinus* with _____ *longifilis*; it is fast-growing and shows some heterosis for growth and survival in Nigerian aquaculture.

5.2.2 Feed technology and alternative protein sources

Fishmeal (dried and ground marine fish) has been the gold standard protein ingredient in aquaculture feeds because of its high protein content (60 to 72 per cent crude protein), excellent amino acid profile, high digestibility, and palatability. However, global fishmeal supply is



limited and its price is volatile; fishmeal can constitute 30 to 50 per cent of total feed cost in catfish diets. The search for alternative protein sources that can partially or fully replace fishmeal is one of the most active research areas in aquaculture nutrition. The main candidates are: soyabean meal (high protein, 40 to 48%; anti-nutritional factors such as trypsin inhibitors must be deactivated by heat treatment); groundnut cake (40 to 50%; widely available in Nigeria; aflatoxin contamination risk requires careful sourcing and storage); and blood meal (80 to 85%; highly digestible; palatability may be low).

Novel alternative protein sources receiving increasing research attention for Nigerian aquaculture include: black soldier fly larvae (*Hermetia illucens*; 40 to 45% crude protein, 30 to 40% fat; can be mass-produced on organic waste, including fish offal and market waste; NIFFR and several Nigerian universities have published trials showing good catfish growth with 25 to 50% black soldier fly meal replacing fishmeal); duckweed (*Lemna* spp.; a floating aquatic plant with 25 to 45% protein on a dry weight basis; can be cultivated in catfish pond effluent, closing a nutrient loop); and maggot meal. Fermentation of plant proteins with *Aspergillus* spp. or other fungi reduces anti-nutritional factors and improves amino acid availability, potentially increasing the usable proportion of plant-based ingredients in fish diets.

Fill in the blank: Black soldier fly larvae (*Hermetia* _____) have 40 to 45 per cent crude protein and can be mass-produced on organic waste; they are a promising fishmeal replacement tested in Nigerian catfish feeding trials.

<u>Protein Source</u>	<u>Crude Protein %</u>	<u>Digestibility</u>	<u>Availability in Nigeria</u>	<u>Limitations/Advantages</u>
Fishmeal	60–72%	Very high	Limited, expensive (import-dependent)	Excellent protein quality; costly and unsustainable
Soyabean meal	40–48%	High (after heat treatment)	Widely available	Affordable, plant-based; anti-nutritional factors if untreated



Groundnut cake	40–45%	Moderate	Locally available	Cheaper; risk of aflatoxin contamination
Blood meal	80–90%	Moderate–high (variable)	Available from abattoirs	Very high protein; poor palatability, low lysine content
Black soldier fly larvae	40–55%	High	Emerging, small-scale production	Sustainable insect protein; limited large-scale supply
Duckweed	25–35%	Moderate	Found in ponds, wetlands	Cheap, renewable; lower protein, seasonal availability

Table 5.1: Comparison of alternative protein sources for catfish and tilapia feeds in Nigeria

5.2.3 Digital and precision aquaculture technologies

Digital and precision technologies are transforming aquaculture management by providing real-time data, reducing labour requirements, and enabling more precise control of the farming environment. Automated feeding systems use sensors and cameras to monitor fish feeding behaviour; feed is dispensed by demand feeders activated by fish breaking a trigger rod, or by time-controlled dispensers calibrated to the fish biomass. These systems reduce feed wastage and labour, improving FCR. Water quality sensors (for DO, pH, temperature, ammonia, and turbidity) connected to data loggers provide continuous monitoring, generating alerts when parameters fall outside the optimal range, enabling rapid corrective action.

Remote monitoring systems (using mobile phone networks or satellite connectivity) allow a farmer or technician to check pond conditions from anywhere, reducing the need for overnight farm presence. Unmanned aerial vehicles (drones) are used for surveillance of large cage culture operations and reservoir fisheries to detect illegal fishing and monitor cage condition.

Geographic information systems (GIS) are used for mapping fish habitats, identifying suitable aquaculture sites, and monitoring changes in water body extent (such as the shrinking of Lake Chad). Computer-aided farm design software enables precise design of pond systems, water supply networks, and RAS components. These technologies are currently more accessible to



large commercial operators; appropriate lower-cost versions (smartphone apps for data recording, affordable DO meters) are increasingly available for small-scale Nigerian farmers.

Fill in the blank: Automated _____ systems connected to sensors that monitor fish feeding activity reduce feed wastage and labour in intensive aquaculture, improving the feed conversion ratio.

Pilot questions 5.2

- Explain what selective breeding is and describe the evidence that it has improved catfish productivity in Nigeria.
- Explain what the "heteroclarias" hybrid is and state two advantages and one limitation of this hybrid for Nigerian catfish farming.
- State three alternative protein sources being investigated for use in catfish feed in Nigeria and give one advantage of each.
- Explain why fishmeal substitution is an important research priority in Nigerian aquaculture.
- Describe two digital technologies that can improve the management of a catfish farm and explain how each works.

5.3 Environmental Sustainability in Fisheries and Aquaculture

5.3.1 Aquatic habitat and ecosystem health

Aquatic habitats are the physical and chemical environments that support fish populations; their health determines the productivity and sustainability of fisheries. Key indicators of aquatic ecosystem health include: water quality (dissolved oxygen, pH, temperature, turbidity, nutrient levels); biodiversity (species richness and abundance of fish, invertebrates, and aquatic plants); habitat structure (the presence of submerged aquatic vegetation, woody debris, riparian vegetation, and substrate complexity that provide spawning, feeding, and nursery habitat); and



hydrological connectivity (the ability of fish to move between habitats for spawning migration, feeding, and seasonal range shifts).

The main threats to aquatic habitat health in Nigeria are: deforestation of riparian vegetation (loss of shade, reduced input of terrestrial organic matter, bank erosion, and increased sedimentation of river channels); agricultural runoff (pesticides and excess fertiliser nutrients causing algal blooms, oxygen depletion, and fish kills); industrial effluent (oil spills in the Niger Delta; heavy metal contamination from mining in the Jos Plateau and Cross River areas); climate change (reduced rainfall causing reduced river flow and lake levels, increasing water temperature); damming and water abstraction (Kainji, Shiroro, and Tiga dams have altered downstream flow regimes and blocked spawning migrations); and overfishing and destructive fishing methods (already covered in Series 4).

Fill in the blank: Deforestation of _____ vegetation around rivers removes shade, reduces organic matter input, causes bank erosion, and increases sedimentation; it is a major threat to aquatic habitat health in Nigeria.

5.3.2 Aquaculture and the environment

Aquaculture has a dual relationship with the environment: it provides an alternative to wild capture fisheries (reducing fishing pressure on wild stocks) while simultaneously generating its own environmental impacts. The main environmental impacts of aquaculture are: water quality degradation from pond effluents (uneaten feed, faeces, and metabolic waste products enrich the water with nitrogen, phosphorus, and organic matter; discharge of pond water into natural water bodies causes eutrophication and oxygen depletion); disease and parasite transmission (escaping or released farmed fish can transfer diseases and parasites to wild populations; non-native farmed species can hybridise with wild relatives); and land use change (conversion of mangroves, wetlands, and coastal habitats to shrimp or fish ponds in coastal areas).

Strategies for reducing the environmental footprint of aquaculture: integrated fish-crop-livestock farming (fish pond effluent is used to irrigate and fertilise crops; crop residues and livestock manure are used to fertilise fish ponds, closing nutrient loops and reducing external inputs); use of constructed wetlands or vegetated buffer zones to treat pond effluent before discharge;



reducing fishmeal use in feed through alternative protein sources (as described in Part 5.2); minimum input or organic aquaculture systems; and environmental impact assessment (EIA) before establishing new large-scale aquaculture operations. In Nigeria, integrated farming of catfish with poultry (poultry litter fertilises the pond), vegetables, and crops is widely practised at small commercial scale as a low-cost sustainability strategy.

Fill in the blank: Integrated fish-crop-livestock farming reduces the environmental footprint of aquaculture by closing _____ loops: pond effluent fertilises crops, and crop residues or livestock manure fertilise the fish pond.

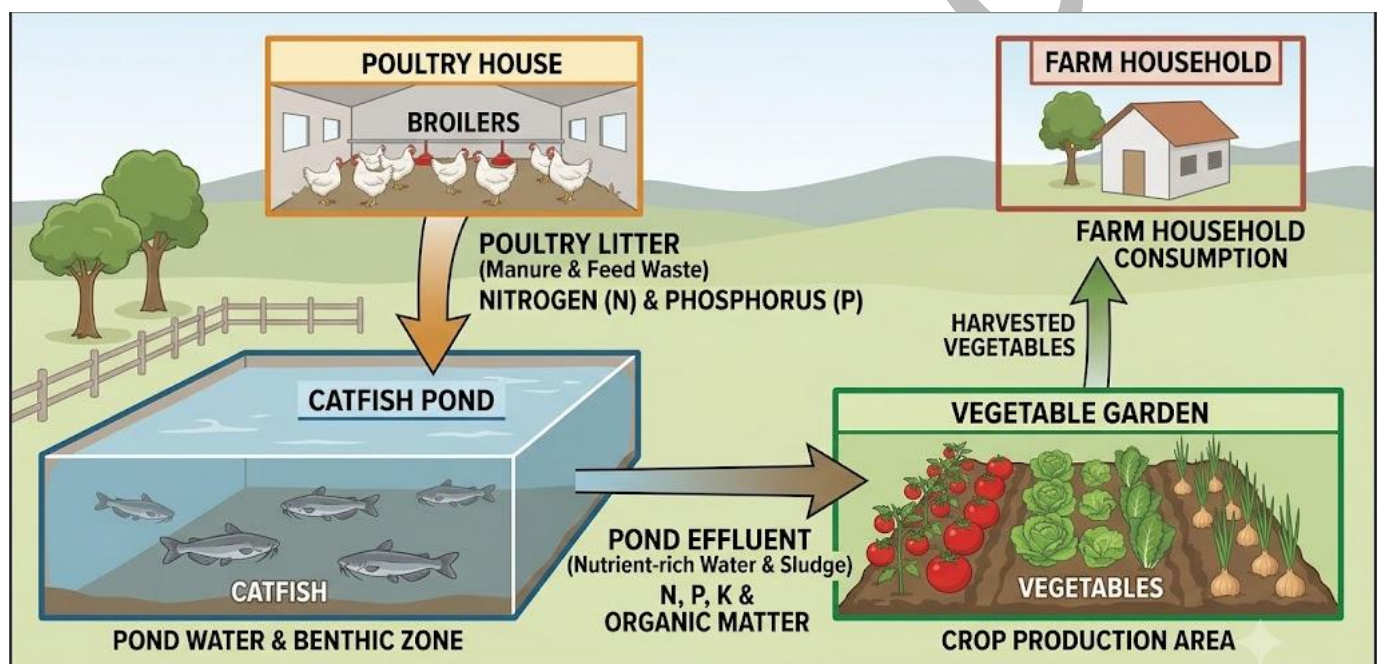


FIGURE 5.2: DIAGRAM OF AN INTEGRATED CATFISH-POULTRY-VEGETABLE FARM SHOWING NUTRIENT FLOWS BETWEEN COMPONENTS

Figure 5.2: Diagram of an integrated catfish-poultry-vegetable farm showing nutrient flows between components

5.3.3 Climate change and Nigerian fisheries

Climate change is already affecting Nigerian fisheries and aquaculture through several pathways. Rising temperatures increase water temperatures in ponds and rivers, reducing dissolved oxygen solubility, accelerating metabolic rates (increasing feed demand), and stressing fish beyond



thermal tolerance limits (optimal temperature for catfish is 25 to 30 degrees Celsius; sustained temperatures above 33 degrees reduce growth and immune function). Changes in rainfall patterns alter river flow regimes, affecting the seasonal flooding that triggers spawning migrations, and reducing the availability of water for pond aquaculture during extended dry seasons. Lake Chad, already reduced to approximately 6 per cent of its 1963 area, is expected to contract further under climate projections, threatening the livelihoods of millions of fishing-dependent people.

Projected future impacts include: increased frequency and intensity of extreme weather events (droughts, floods, tropical storms) disrupting farming operations and capture fisheries; northward shift of optimal habitat for warm-water fish species, affecting species distribution and fisheries productivity in different zones; increased incidence of harmful algal blooms (cyanobacteria) in warming water bodies; and acidification of coastal marine environments affecting shellfish and reef fish. Adaptation strategies include: development of heat-tolerant and drought-resilient fish strains through selective breeding; diversification of aquaculture systems (RAS allows temperature control; cage culture in deeper reservoir waters is cooler); improving water storage and irrigation infrastructure for dry-season aquaculture; and developing early warning systems for extreme weather events to allow farmers to take protective action.

Fill in the blank: Rising temperatures from climate change reduce _____ solubility in pond water and stress fish beyond their thermal tolerance limits; sustained temperatures above 33 degrees Celsius reduce catfish growth and immune function.

<u>Climate Change Impact</u>	<u>Adaptation Strategy</u>
Rising water temperatures	Select heat-tolerant species (e.g., catfish), adjust stocking densities, improve aeration systems
Erratic rainfall and flooding	Construct raised ponds, improve drainage, adopt flood-resistant pond designs
Drought and reduced water availability	Use water-efficient systems (recirculating aquaculture), harvest rainwater, diversify water sources
Changes in fish migration and stock distribution	Strengthen monitoring of capture fisheries, regional cooperation for shared stocks



Increased disease outbreaks	Enhance biosecurity, regular water quality monitoring, vaccination/prophylaxis where available
Loss of coastal habitats (mangroves, estuaries)	Promote mangrove restoration, integrated coastal zone management
Reduced productivity and food security risks	Diversify aquaculture species, improve feed efficiency, invest in climate-smart aquaculture practices

Box 5.1: Summary of climate change impacts and adaptation strategies for Nigerian fisheries and aquaculture

Pilot questions 5.3

1. State five indicators of aquatic ecosystem health.
2. Describe three human activities that threaten aquatic habitat health in Nigeria.
3. Explain three environmental impacts of aquaculture on natural water bodies.
4. Describe two strategies for reducing the environmental footprint of aquaculture in Nigeria.
5. Explain how rising temperatures from climate change affect catfish aquaculture in Nigeria.

5.4 Professional Skills and the Fisheries Graduate

5.4.1 Information retrieval and use of scientific literature

The ability to retrieve, read, and critically evaluate scientific literature is a fundamental professional competency. The primary sources of fisheries and aquaculture research are: peer-reviewed journals (for example, Aquaculture; Aquaculture Nutrition; Journal of Applied Aquaculture; Fisheries Research; Reviews in Aquaculture; African Journal of Agricultural Research); conference proceedings; and theses and dissertations. Databases for accessing literature include: Google Scholar (free, comprehensive); Web of Science and Scopus



(subscription-based, more curated); FAO Aquatic Sciences and Fisheries Abstracts (ASFA; specialised for fisheries); and ResearchGate (for accessing preprints and author-shared full texts).

Critical reading of a scientific paper requires evaluating: the research question (is it clearly stated and relevant?); the methods (are they appropriate, controlled, and reproducible?); the sample size (is it large enough to detect real differences?); the statistical analysis (are the tests appropriate for the data?); the results (do the data actually support the conclusions drawn by the authors?); and the limitations (what are the constraints on generalising the findings?). A fisheries student should practise reading at least one journal article per week in their area of study, summarising it in their own words, and connecting its findings to the course content. Citing sources correctly using an accepted citation style (APA, Harvard, or Vancouver) is required in academic writing.

Fill in the blank: _____ Scholar is a free online database for accessing fisheries and aquaculture scientific literature; ASFA (Aquatic Sciences and Fisheries Abstracts) is a specialised database curated specifically for fisheries science.

5.4.2 Oral and written presentation of scientific findings

Oral presentation of scientific findings follows a structured format: introduction (why was the study done? what is the research gap?); materials and methods (how was the study done?); results (what was found, presented with graphs and tables?); discussion (what do the results mean in the context of existing knowledge?); and conclusion (what are the key take-home messages and recommendations?). Effective oral presentation requires: preparing clear, uncluttered slides (one main point per slide; relevant graph or photo rather than dense text); practising within the allotted time; speaking clearly and at a pace that allows the audience to follow; and preparing for questions from the audience.

Written scientific communication takes the form of: a thesis or dissertation (long-form, comprehensive, with literature review, methodology, results, and discussion chapters); a journal article (structured as introduction, methods, results, and discussion, typically 4,000 to 8,000 words); a technical report (more accessible style, for extension workers, government agencies, or funders); and a conference abstract (a 200 to 400 word summary of the key findings). All written scientific communication must be clear, precise, objective, and supported by data and references.



Plagiarism (presenting another person's words or ideas as one's own without attribution) is a serious academic offence that can result in the cancellation of a degree. Using paraphrasing, quotation, and correct citation avoids plagiarism.

Fill in the blank: A scientific oral presentation follows the sequence: introduction, materials and methods, _____, discussion, and conclusion; each section serves a distinct communication purpose.

5.4.3 Career pathways in fisheries and aquaculture

A graduate with a degree in aquaculture and fisheries management can pursue diverse career pathways. In the public sector: fisheries officer or stock assessment scientist in the Federal Department of Fisheries or a state fisheries department (policy, licensing, enforcement, extension); research scientist at NIFFR, NIOMR, or a university (conducting and publishing research); environmental officer in the National Environmental Standards and Regulations Enforcement Agency (NESREA) or the National Oil Spill Detection and Response Agency (NOSDRA) addressing aquatic environmental issues; and extension officer (disseminating improved aquaculture and fisheries management practices to farmers and fishing communities).

In the private sector: commercial catfish farmer or fish farm manager (operating or managing a grow-out or hatchery facility); aquaculture input supplier (feed, fingerling, equipment, and chemical distribution); fish processor and exporter (smoking, freezing, and distributing fisheries products domestically or internationally); consultant (providing technical advisory services to fish farmers, investors, NGOs, and government); and trainer or facilitator (delivering training programmes for farmer groups, cooperatives, and extension workers). International opportunities exist with FAO, WorldFish, CGIAR centres, and international conservation organisations.

Academic pursuit (MSc, PhD) at Nigerian and international universities prepares graduates for research and teaching careers. The breadth of opportunities reflects the strategic importance of fisheries and aquaculture to Nigerian food security and the economy.

Fill in the blank: A fisheries graduate in the public sector may serve as a research scientist at NIFFR or NIOMR, as a fisheries officer in the Federal _____ of Fisheries, or as an environmental officer with NESREA or NOSDRA.



<u>Category</u>	<u>Career Pathways</u>
Public Sector	Fisheries officers in Federal/State Ministries, extension agents, aquaculture development programs, regulatory and policy roles
Private Sector	Fish farm managers, hatchery operators, feed mill specialists, aquaculture consultants, seafood processing and marketing enterprises
International Organizations	Roles in FAO, WorldFish, NGOs, regional fisheries commissions, climate change and sustainability projects
Academic/Research	University lecturers, research scientists, technical trainers, extension educators, innovation in aquaculture technologies

Box 5.2: Career pathways for Nigerian fisheries and aquaculture graduates

Pilot questions 5.4

1. Name four databases or sources a fisheries student can use to access scientific literature.
2. Describe the key questions a student should ask when critically reading a fisheries journal article.
3. Describe the structure of a scientific oral presentation in fisheries research.
4. Explain what plagiarism is and describe two ways of avoiding it in scientific writing.
5. State five career pathways available to a Nigerian fisheries and aquaculture graduate.

Series Summary

This final Series completed the course by covering research methods, innovation, environmental sustainability, and professional skills. We described four types of fisheries research (basic, applied, adaptive, action), the steps of the scientific method (observation through dissemination), data collection methods (pond trials, field surveys, biological sampling, water quality measurement, questionnaires, acoustics), and the statistical tools required (descriptive statistics, t-test, ANOVA, regression) and data presentation conventions (tables, bar charts, line graphs, scatter plots). We described innovations in genetic improvement (selective breeding of catfish,



heteroclaras hybrid, marker-assisted selection, triploid induction, monosex tilapia), feed technology (alternative proteins: soyabean, groundnut cake, blood meal, black soldier fly larvae, duckweed), and digital aquaculture (automated feeders, water quality sensors, remote monitoring, drones, GIS).

We explained aquatic habitat health and the key threats in Nigeria (deforestation, agricultural runoff, industrial effluent, climate change, damming), the environmental impacts of aquaculture (eutrophication, disease transmission, habitat conversion) and mitigation strategies (integrated farming, constructed wetlands, alternative feeds, EIA), and the impacts of climate change on Nigerian fisheries (rising temperatures, changing rainfall, Lake Chad contraction, extreme weather) with adaptation strategies. Finally, we covered scientific literature retrieval (Google Scholar, ASFA, peer-reviewed journals, critical reading), oral and written scientific presentation (introduction-methods-results-discussion-conclusion structure), and career pathways for fisheries graduates in Nigeria. By completing this Series and the full course, you should be able to achieve all seven Series Learning Outcomes (SLO 5.1 to SLO 5.7) and all eleven course learning outcomes.

Glossary of Terms

1. **Action research:** research conducted in direct collaboration with farmers or practitioners to identify and solve problems in real production settings; findings are immediately applicable.
2. **Adaptive research:** research that tests technologies proven elsewhere under local conditions to assess their suitability for a specific environment or farming system.
3. **Analysis of variance (ANOVA):** a statistical test that compares the means of three or more treatment groups to determine whether differences are statistically significant.
4. **Applied research:** research directed at solving a specific practical problem, such as formulating a new catfish feed or developing a disease treatment protocol.



5. **Aquatic ecosystem health:** the condition of an aquatic environment assessed through water quality, biodiversity, habitat structure, and hydrological connectivity indicators.
6. **ASFA (Aquatic Sciences and Fisheries Abstracts):** a specialised bibliographic database curated by FAO covering fisheries and aquatic science literature.
7. **Basic research:** fundamental scientific investigation aimed at generating knowledge without immediate practical application; the foundation for applied research.
8. **Black soldier fly larvae (*Hermetia illucens*):** insect larvae with 40-45% crude protein; mass-produced on organic waste and investigated as a fishmeal replacement in Nigerian catfish diets.
9. **Climate adaptation:** adjustments in farming practices, crop (or species) selection, and infrastructure in response to observed or projected climate change impacts.
10. **Eutrophication:** the enrichment of a water body with nutrients (nitrogen and phosphorus) causing excessive algal growth, oxygen depletion, and biodiversity loss.
11. **GIS (Geographic Information System):** computer-based tools for capturing, storing, analysing, and displaying geographic data; used in fisheries for habitat mapping and aquaculture site selection.
12. **Genetic improvement:** the use of selective breeding, hybridisation, or molecular tools to increase the productive performance of farmed fish populations.
13. **Heteroclarias:** the hybrid produced by crossing *Clarias gariepinus* (female) with *Heterobranchius longifilis* (male); fast-growing and showing some heterosis for growth and survival.
14. **Integrated farming:** a farming system that combines fish culture with livestock and/or crop production to recycle nutrients, reduce inputs, and improve farm sustainability.
15. **Marker-assisted selection (MAS):** the use of DNA markers associated with genes for target traits to identify and select superior individuals without waiting for phenotypic expression.



16. **Peer-reviewed journal:** a scientific publication in which submitted articles are evaluated by independent experts in the field before acceptance for publication; the gold standard for research communication.
17. **Plagiarism:** the presentation of another person's words, ideas, or data as one's own without acknowledgement; a serious academic offence.
18. **Precision aquaculture:** the application of sensors, data analytics, automation, and digital technologies to monitor and optimise aquaculture production in real time.
19. **Regression analysis:** a statistical method that quantifies the relationship between two or more variables, allowing prediction and the identification of cause-and-effect relationships.
20. **Riparian vegetation:** the plants growing along the banks of rivers, lakes, and streams; critical for water quality, bank stabilisation, shading, and organic matter input.
21. **Selective breeding:** the process of choosing parents with superior phenotypic performance for breeding, with the aim of increasing the frequency of favourable alleles in the next generation.
22. **Standard deviation:** a measure of the spread of values around the mean in a dataset; a large standard deviation indicates high variability among individuals.
23. **Standard error:** the standard deviation of the sampling distribution of the mean; indicates the precision of the sample mean as an estimate of the population mean.
24. **Stock assessment:** the scientific evaluation of the abundance, growth, mortality, and reproduction of a fish stock to provide advice for management decisions.
25. **Triploid fish:** fish produced by chromosome set manipulation (pressure or thermal shock of fertilised eggs) that have three sets of chromosomes instead of two; typically sterile and thus divert energy from reproduction to growth.

Concept Check Questions [Series 5]



Objective Questions

1. _____ research tests technologies proven elsewhere under local Nigerian conditions; an example is evaluating a foreign catfish strain for growth performance in Nigerian ponds. (Linked to SLO 5.1)
2. Analysis of variance (ANOVA) is used when comparing the means of _____ or more treatment groups in an aquaculture feeding trial. (Linked to SLO 5.2)
3. The "heteroclarias" hybrid is produced by crossing *Clarias gariepinus* with *Heterobranchus* _____. (Linked to SLO 5.3)
4. Integrated fish-crop-livestock farming reduces the environmental footprint of aquaculture by closing _____ loops between pond effluent, crops, and livestock. (Linked to SLO 5.5)
5. Rising temperatures from climate change reduce dissolved oxygen _____ in pond water and stress fish beyond their thermal tolerance limits. (Linked to SLO 5.6)

Short-Answer Questions

- Distinguish between basic, applied, and adaptive research in fisheries and give one example of each. (Linked to SLO 5.1)
- State three alternative protein sources being investigated for catfish feed in Nigeria and give one advantage of each. (Linked to SLO 5.3)
- Describe three environmental impacts of aquaculture on natural water bodies. (Linked to SLO 5.5)
- State four observed or projected impacts of climate change on Nigerian fisheries and aquaculture. (Linked to SLO 5.6)
- Describe the structure of a scientific oral presentation and explain the purpose of each section. (Linked to SLO 5.7)

Long-Answer Questions



1. Describe the types of fisheries research, the scientific method, data collection methods, and the statistical tools and data presentation conventions used in fisheries and aquaculture research in Nigeria. (Linked to SLOs 5.1, 5.2)
2. Describe the major innovations in genetic improvement, feed technology, and digital aquaculture relevant to Nigerian fish farming, and evaluate the potential of these innovations to improve aquaculture productivity and sustainability. (Linked to SLO 5.3)
3. Describe the importance of aquatic habitat health and the major threats in Nigeria, evaluate the environmental impacts of aquaculture and strategies to reduce them, and assess the impacts of climate change on Nigerian fisheries and aquaculture with reference to adaptation strategies. (Linked to SLOs 5.4, 5.5, 5.6)

Answers to Concept Check Questions [Series 5]

Objective Questions

6. Adaptive.
7. Three.
8. Longifilis.
9. Nutrient.
10. Solubility.

Short-Answer Questions

11. Basic research: investigates biological principles without immediate application; example: studying reproductive physiology of wild *Clarias* to understand natural spawning triggers. Applied research: addresses a specific practical problem; example: testing different doses of Ovaprim for optimal spawning induction in hatchery catfish. Adaptive research: tests technologies proven elsewhere under local conditions; example:



evaluating a fast-growing catfish strain developed in Germany for growth rate and disease resistance in Nigerian pond conditions.

12. Any three with advantages: soyabean meal (40-48% crude protein; widely available in Nigeria; cheaper than fishmeal; heat treatment deactivates anti-nutritional factors); groundnut cake (40-50% crude protein; locally abundant and affordable; familiar to Nigerian feed millers); black soldier fly larvae (40-45% crude protein; produced from organic waste at low cost; trials at NIFFR show good catfish growth when replacing 25-50% fishmeal).
13. Any three: water quality degradation from pond effluents (uneaten feed and faeces add nitrogen and phosphorus to receiving water bodies causing eutrophication and oxygen depletion); disease and parasite transmission from farmed fish to wild populations if escapes occur; land use change from conversion of mangroves, wetlands, and coastal habitats to aquaculture ponds, destroying coastal nursery ecosystems.
14. Any four: rising water temperatures reducing dissolved oxygen and stressing catfish above 33 degrees Celsius; changing rainfall patterns reducing river flow and flooding that triggers spawning migrations; extended dry seasons reducing water availability for pond aquaculture; Lake Chad contraction threatening the livelihoods of millions of fishing-dependent people in north-eastern Nigeria; increased frequency of extreme weather events (floods, droughts) disrupting farming and capture fisheries.
15. Introduction: states why the study was done, identifies the research gap, and states the objectives; Materials and methods: describes how the study was conducted in sufficient detail for replication; Results: presents what was found using graphs and tables without interpretation; Discussion: interprets the results in the context of existing literature and explains what the findings mean; Conclusion: states the key take-home messages and practical recommendations arising from the study.

Long-Answer Questions

1. Types: basic (fundamental knowledge, e.g. fish population genetics); applied (specific problem, e.g. new feed formula); adaptive (test foreign technology locally, e.g. European



catfish strain in Nigeria); action (farmer-participatory, immediate adoption). Stock assessment research (population abundance, growth, mortality for management advice); environmental monitoring (water quality, habitat, biodiversity trends); socioeconomic research (livelihoods, gender, markets, policy). Scientific method: observation and problem identification; literature review; hypothesis formulation; experimental design; data collection; data analysis; interpretation and conclusion; dissemination. Data collection methods: experimental pond/tank trials (replicated treatment groups); field surveys (standardised gear/effort); biological sampling (length, weight, age from otoliths, reproductive state); water quality measurement (calibrated instruments: DO, pH, temperature, ammonia, turbidity); questionnaire surveys (socioeconomic data); remote sensing and acoustics (sonar, echo-sounding, satellite imagery). Statistics: descriptive (mean, median, standard deviation, standard error); inferential (t-test: two groups; ANOVA: three or more groups, most common in feed trials; regression: relationship between two continuous variables). Data presentation: tables (exact values, means, standard deviation, sample size); bar charts (compare means across treatment categories); line graphs (trends over time, growth curves); scatter plots (two continuous variables, weight-length relationship); pie charts (proportional composition). Conventions: all graphs need title, labelled axes with units, legend.

2. Genetic improvement: selective breeding (superior parents selected for fast growth, disease resistance, feed efficiency; NIFFR programmes show 20-40% growth improvement in improved catfish strains over unselected local strains); heteroclaris hybrid (*Clarias gariepinus* female x *Heterobranchus longifilis* male; fast-growing, some heterosis for growth and survival; reduced fertility may be a limitation); molecular tools (marker-assisted selection using DNA markers for target trait genes; genomic selection from thousands of DNA markers); chromosome manipulation (triploid induction by pressure or temperature shock; sterile fish divert energy from reproduction to growth); sex reversal (monosex male tilapia by methyltestosterone; faster growth, no early reproduction problem). Feed technology: fishmeal (60-72% CP; limited supply, volatile price; 30-50% of catfish feed cost); alternatives: soyabean meal (40-48%, heat-treat anti-nutritionals); groundnut cake (40-50%, aflatoxin risk); blood meal (80-85%, palatability issue); black soldier fly larvae *Hermetia illucens* (40-45%, produced from organic waste,



NIFFR trials 25-50% fishmeal replacement with good catfish growth); duckweed Lemna (25-45% dry weight, cultivated in pond effluent, closes nutrient loop); fermentation with *Aspergillus* reduces anti-nutritional factors. Digital/precision aquaculture: automated feeding systems (sensors/cameras monitor feeding behaviour; demand feeders reduce waste, improve FCR); water quality sensors (DO, pH, temperature, ammonia, turbidity; continuous monitoring with alerts; real-time corrective action); remote monitoring (mobile/satellite connectivity; farm checking without physical presence); drones (surveillance of cage culture; illegal fishing detection); GIS (habitat mapping, site selection, Lake Chad monitoring); farm design software (RAS and pond system design). Collectively these innovations can substantially improve productivity and reduce the environmental footprint of Nigerian aquaculture if made accessible at appropriate cost to small and medium farmers.

3. Aquatic habitat health: indicators (water quality: DO, pH, turbidity, nutrients; biodiversity: species richness and abundance; habitat structure: submerged vegetation, woody debris, riparian cover, substrate complexity; hydrological connectivity: fish movement between habitats). Major threats in Nigeria: deforestation of riparian vegetation (loss of shade, bank erosion, sedimentation); agricultural runoff (pesticides and nutrient pollution causing algal blooms, fish kills); industrial effluent (oil spills in Niger Delta, heavy metals from mining in Jos Plateau and Cross River); climate change (reduced rainfall, lower flows, higher water temperatures); damming and water abstraction (altered downstream flows, blocked spawning migrations); overfishing and destructive gears (already covered). Environmental impacts of aquaculture: water quality degradation from pond effluents (N, P, organic matter causing eutrophication and DO depletion in receiving waters); disease and parasite transmission from escaped farmed fish to wild populations; land use change (mangrove and wetland conversion to aquaculture ponds, loss of nursery habitat). Mitigation strategies: integrated fish-crop-livestock farming (pond effluent irrigates crops, crop residues or livestock manure fertilise pond, closes nutrient loops; widely practised in Nigeria); constructed wetlands or vegetated buffer zones between pond and natural water body to treat effluent; reducing fishmeal use through alternative proteins (reducing pressure on wild forage fish stocks); minimum-input/organic aquaculture; EIA before large new operations. Climate change



impacts on Nigeria: rising temperatures (reduce DO solubility; catfish optimal 25-30 degrees Celsius; above 33 degrees growth and immunity impaired); changing rainfall (altered river flow patterns, reduced pond water availability in dry season); Lake Chad contraction (from 25,000 km² in 1963 to ~1,500 km² today; climate change and water abstraction; millions of livelihoods threatened); extreme weather events (floods, droughts, storms disrupting farming and fisheries); harmful algal blooms (cyanobacteria in warming water bodies). Adaptation: selective breeding of heat-tolerant catfish strains; RAS for temperature control; cage culture in deeper cooler reservoir waters; improved water storage infrastructure for dry-season supply; fisheries diversification; early warning systems for extreme events.

Answers to Pilot Questions [Series 5]

Part 5.1: Research Methods

6. Basic: investigates fundamental biological principles without a specific applied objective; Nigerian example: studying the reproductive endocrinology of *Clarias gariepinus* to understand the hormonal cascade triggering natural spawning, with no immediate aquaculture application but laying the groundwork for improved hatchery protocols. Applied: addresses a specific, immediate practical problem; Nigerian example: comparing the growth performance and FCR of catfish fed a diet with 25% black soldier fly meal versus a conventional fishmeal diet, to determine whether the alternative ingredient can replace fishmeal economically. Adaptive: tests a technology proven elsewhere in a different local context; Nigerian example: evaluating a fast-growing catfish strain developed and selected in a Dutch selective breeding programme for its growth rate, disease susceptibility, and survival in typical Nigerian earthen pond conditions. Action: conducted in collaboration with farmers or communities to solve their specific problems; Nigerian example: working with fish farmers in Oyo State to diagnose



the cause of recurring catfish mortality in their ponds, test an integrated pond management solution on their farms, and help farmers adopt the improved practice.

7. Steps applied to an aquaculture feeding trial: (1) Observation: a catfish farmer notices that growth rates are lower than expected despite adequate feeding; possible cause is suboptimal dietary protein level. (2) Literature review: existing publications on catfish protein requirements are reviewed to establish what protein levels have previously been tested and what results were obtained. (3) Hypothesis: catfish fed a diet containing 40% crude protein will have significantly higher final body weight after 8 weeks than catfish fed 30% or 35% crude protein diets. (4) Experimental design: 150 catfish of uniform initial weight (10 g) are randomly allocated to 9 tanks (3 tanks per treatment = 3 replicates per dietary protein level: 30%, 35%, 40%); all other conditions (stocking density, water quality, feeding rate, management) are identical across tanks. (5) Data collection: all fish are weighed at the start and end of the trial; feed consumption per tank is recorded daily; mortality is counted and removed daily; water quality is measured twice weekly. (6) Data analysis: mean final weight and FCR are calculated for each treatment; one-way ANOVA is used to test for significant differences among treatments; Tukey's post-hoc test identifies which specific pairs of treatments differ significantly. (7) Interpretation: if the 40% CP group shows significantly higher weight than both other groups, the hypothesis is supported; if no significant difference is found between 35% and 40% CP groups, the lower protein level is recommended on cost grounds. (8) Dissemination: results are written up as a journal article or extension bulletin and presented at a conference or farmer meeting.
8. A t-test is used when comparing the means of exactly two groups to determine whether they differ significantly (for example, comparing mean final weight of catfish in a treatment pond versus a control pond; or comparing growth rates before and after a feeding regime change in the same pond). An ANOVA is used when comparing the means of three or more groups simultaneously (for example, comparing mean final weight of catfish fed three different protein levels: 30%, 35%, and 40%); ANOVA is preferred over multiple t-tests between all pairs because conducting multiple t-tests inflates the probability of falsely finding a significant difference by chance (Type I error).



9. A bar chart uses vertical or horizontal bars to represent the mean values of a categorical variable (for example, mean final weight of catfish at three protein levels); it is used when the main comparison is between discrete categories or treatment groups; error bars can be added to show standard deviation or standard error. A line graph plots data points connected by lines and shows how a continuous variable changes over time or along another continuous variable axis (for example, mean body weight of catfish sampled every two weeks over a 16-week production cycle); it is used when the primary interest is in trends, trajectories, or relationships over a continuum.
10. Standard deviation (SD) measures the spread or variability of individual values around the sample mean; a large SD indicates that individual fish in the group vary widely in their measured characteristic (for example, if mean catfish weight is 500 g with SD = 150 g, many fish are 350 g or 650 g; high variability may indicate size variation from uneven feeding or grading failure). Standard error (SE) measures the precision of the sample mean as an estimate of the true population mean; it is calculated as SD divided by the square root of the sample size; a small SE indicates that the sample mean is a reliable estimate of the true mean; SE is used in constructing confidence intervals and in statistical testing. In presenting aquaculture trial results, means are typically reported as "mean $\pm$ SD" (to show within-group variation) or "mean $\pm$ SE" (to show precision of the mean estimate).

Part 5.2: Innovation and Technology

11. Selective breeding in aquaculture is the deliberate process of choosing parents with superior phenotypic performance (faster growth, better disease resistance, higher feed efficiency) for reproduction and using only their offspring for the next generation of production or selection; by repeating this cycle over multiple generations, the frequency of favourable alleles in the farmed fish population increases and average performance improves. Evidence for improved catfish productivity in Nigeria: selective breeding programmes at NIFFR (New Bussa) and several Nigerian universities have produced improved strains of *Clarias gariepinus* that show 20 to 40 per cent higher growth rates



than unselected local strains under the same feeding and management conditions; this improvement in growth rate directly reduces production cycle length and feed cost per kg of fish, improving farm profitability.

12. The "heteroclarias" hybrid is produced by crossing a female *Clarias gariepinus* (African catfish) with a male *Heterobranchus longifilis* (African catfish with a dorsal adipose fin and broader head); the resulting F1 offspring combine traits from both parent species. Two advantages: (1) fast growth: the hybrid typically grows faster than the pure *Clarias gariepinus* under similar conditions, reaching market weight earlier and reducing production cycle length; (2) some heterosis: the F1 hybrid shows hybrid vigour for growth and survival, meaning it outperforms the average of its two parents, similar to hybrid vigour seen in plant breeding. One limitation: the hybrid has reduced or absent fertility (most heteroclarias are sterile or have very low fecundity), meaning the farmer cannot produce hybrid fingerlings from the hybrid itself and must always purchase from a hatchery that maintains the pure *Clarias* female and *Heterobranchus* male parent lines; this creates a dependency on a reliable, quality hatchery supply.
13. Any three with advantages: (1) soyabean meal: 40 to 48% crude protein; widely cultivated and commercially processed in Nigeria; significantly cheaper than fishmeal; can replace up to 40% of fishmeal in catfish diets after heat treatment to deactivate anti-nutritional factors (trypsin inhibitors and haemagglutinins); (2) groundnut cake: 40 to 50% crude protein; a major agricultural by-product in northern Nigeria; locally abundant, affordable, and familiar to Nigerian feed producers; its lysine content complements the methionine content of blood meal, allowing a combination to replace fishmeal; (3) black soldier fly larvae (*Hermetia illucens*): 40 to 45% crude protein; can be mass-produced on agricultural and fish processing waste at low cost; trials at NIFFR and Nigerian universities show good catfish growth when black soldier fly meal replaces 25 to 50% of fishmeal without significant reduction in growth rate or FCR.
14. Fishmeal substitution is an important research priority in Nigerian aquaculture for three reasons: (1) cost: fishmeal constitutes 30 to 50% of total production cost in intensive catfish diets; its price is volatile because it is largely imported and linked to global marine fish stock availability and international demand; reducing fishmeal use through cheaper local alternatives (soyabean meal, groundnut cake, black soldier fly larvae) directly



reduces feed cost and improves farm profitability; (2) supply security: Nigeria's aquaculture sector cannot sustainably depend on an imported ingredient for its main feed protein source; developing locally produced alternatives reduces vulnerability to foreign exchange crises and supply chain disruptions; (3) environmental sustainability: fishmeal is produced from wild marine fish (primarily forage fish like sardines and anchovies); heavy global demand for fishmeal by aquaculture contributes to overfishing of these species; replacing fishmeal with plant and insect proteins reduces the ecological footprint of aquaculture.

15. Any two: (1) Automated feeding systems: sensors or cameras are positioned above the fish tank or pond to monitor fish feeding activity (some systems detect feed pellets floating uneaten at the surface; others use acoustic or image-processing sensors to detect when fish are actively feeding); when a signal indicates that the fish are still feeding, a demand feeder dispenses a small additional portion; when uneaten feed is detected, feeding stops; this system ensures fish receive feed exactly at their appetite, preventing both overfeeding (which wastes expensive feed and degrades water quality) and underfeeding (which slows growth); the result is improved FCR and reduced labour for manual feeding. (2) Water quality sensors with remote monitoring: sensors for dissolved oxygen, pH, temperature, ammonia, and turbidity are installed in the pond or tank and connected to a data logger; readings are transmitted in real time via mobile phone network to a smartphone app on the farmer's phone; the farmer receives an alert if any parameter falls outside the preset optimal range; the farmer can take corrective action immediately (start aerators, open water inlet, reduce feed) without being physically present at the farm; this reduces overnight labour requirements and prevents mortality events from undetected water quality crises.

Part 5.3: Environmental Sustainability

1. Any five indicators: dissolved oxygen concentration (DO; low DO indicates organic pollution or algal die-off; should be >5 mg/L for healthy freshwater ecosystems); pH (should be 6.5-8.5 for most freshwater systems; extremes indicate acid mine drainage or



excessive algal photosynthesis); water turbidity (excessive turbidity from sedimentation or algal blooms reduces light penetration and submerged vegetation, degrading habitat quality); species richness and biodiversity index (healthy aquatic ecosystems have high species diversity; a decline in species richness or the disappearance of sensitive species indicates degradation); presence and extent of submerged aquatic vegetation and riparian plant cover (provides spawning habitat, cover, and organic matter input; its loss is a strong indicator of habitat degradation); hydrological connectivity (the ability of fish to migrate seasonally between habitats; blocked by dams, culverts, and water abstraction).

2. Any three: deforestation of riparian vegetation (clearing trees and shrubs along river banks removes shading that moderates water temperature; eliminates input of terrestrial leaf litter and insects that form a major food base for riverine fish; causes bank erosion, which increases suspended sediment load and turbidity; sediment clogs gravel spawning beds and buries benthic invertebrate communities). Agricultural runoff (application of pesticides and excess nitrogen and phosphorus fertilisers on farms adjacent to rivers and lakes; pesticides kill aquatic invertebrates and fish directly; excess nutrients cause eutrophication in slow-moving water bodies, algal blooms, oxygen depletion, and fish kills). Industrial effluent and pollution (the Niger Delta experiences chronic and acute oil spills from pipeline leaks and sabotage, killing fish, destroying mangrove habitats, and contaminating water used by fishing communities; mining operations in the Jos Plateau and Cross River areas discharge acid mine drainage and heavy metal-contaminated water into rivers, killing fish and making water bodies uninhabitable for decades).
3. Rising temperatures from climate change affect catfish aquaculture in Nigeria through three main mechanisms: (1) reduced dissolved oxygen: warm water holds less dissolved oxygen; as temperatures rise above 30 degrees Celsius in Nigerian ponds and tanks, DO falls toward the critical threshold of 4 mg/L, forcing catfish to supplement gill breathing with air-breathing; sustained low DO impairs growth, suppresses appetite, and increases susceptibility to bacterial infections; farmers must invest in more frequent aeration; (2) direct thermal stress: catfish grow optimally at 25 to 30 degrees Celsius; sustained temperatures above 33 degrees Celsius (increasingly common in southern Nigerian summers) reduce feeding rate, growth rate, and immune function; fish at the thermal limit are more susceptible to disease; (3) reduced water availability for pond aquaculture:



higher temperatures increase evaporation from ponds, increasing the water required to maintain pond levels; combined with altered (and often reduced) rainfall in the dry season, this reduces the ability of ponds to maintain adequate water depth and quality during the critical dry period from November to April in northern Nigeria.

4. Any two strategies: (1) Integrated fish-crop-livestock farming: the nutrient-rich water from catfish ponds is used to irrigate and fertilise adjacent vegetable or crop plots (pond effluent contains ammonia and phosphorus from fish waste, which are plant nutrients); crop residues and vegetable waste are fed back to the fish as supplementary feed; livestock (poultry or pigs) are housed on platforms above or adjacent to the pond so their manure drops or is washed into the pond, fertilising phytoplankton growth (natural food for the fish) and reducing the need for inorganic fertiliser; this integrated system closes nutrient loops, reduces external input costs, generates multiple income streams from one land area, and greatly reduces the quantity of nutrient-rich effluent discharged into natural water bodies. (2) Constructed wetlands or vegetated buffer strips: pond effluent is discharged first into a constructed wetland planted with water hyacinth, vetiver grass, or other nutrient-absorbing plants before being released into a natural water body; the plants absorb the excess nitrogen and phosphorus from the effluent, converting it into plant biomass that can be harvested for livestock feed or compost; this biological treatment system significantly reduces the nutrient loading and organic matter reaching rivers and lakes.
5. Any five from text: stock assessment research; environmental monitoring; socioeconomic research; experimental pond trials; field surveys; biological sampling; water quality measurement; questionnaire surveys; remote sensing and acoustic methods.

Part 5.4: Professional Skills

1. Any four: Google Scholar (free, comprehensive, accessible to all students with internet access); Web of Science (subscription-based, curated, high-quality journals); Scopus (subscription-based, broader coverage including African journals); ASFA (Aquatic Sciences and Fisheries Abstracts, FAO-curated, specialised for fisheries and aquaculture);



ResearchGate (platform for accessing author-shared preprints and full texts); Nigerian university library databases; FAO online library (iLibrary); African Journals Online (AJOL, African journal aggregator).

2. Key questions when critically reading a fisheries journal article: (1) Is the research question clearly stated, relevant, and original? Does it address a genuine gap in knowledge? (2) Are the methods appropriate for the research question? Are they described in sufficient detail to allow replication? (3) Is the sample size adequate to detect real differences, or is the study underpowered? (4) Are the statistical analyses appropriate for the type of data and the number of treatment groups? Are the assumptions of the statistical tests met? (5) Do the data in the results section actually support the conclusions drawn by the authors in the discussion and conclusion sections? Are there alternative interpretations of the data? (6) Are the limitations of the study clearly acknowledged? Under what conditions or contexts can the findings be generalised, and where should they not be applied?
3. Structure and purpose of each section: Introduction (explains the context and importance of the topic; identifies the specific gap in knowledge that the study addresses; states the specific objectives or hypotheses of the study; prepares the audience to understand why the study was needed). Materials and methods (describes exactly how the study was conducted; includes experimental design, species, treatments, replication, data collection procedures, and statistical analysis; must be detailed enough for another researcher to replicate the study). Results (presents what was found, using tables and graphs with appropriate statistical analysis; no interpretation or comparison with other studies; only the data from this study). Discussion (interprets the results in the context of the existing literature; explains why the results were obtained; compares with other studies; addresses unexpected findings; acknowledges limitations). Conclusion (concisely states the most important findings and their practical or scientific significance; provides specific recommendations for practice or future research).
4. Plagiarism is the presentation of another person's words, ideas, data, or creative work as one's own without acknowledgement or attribution; it is a serious academic and professional offence that can result in the cancellation of a degree, retraction of a publication, and damage to professional reputation. Two ways to avoid plagiarism: (1)



paraphrasing with citation: when using another author's idea or finding, express it in your own words using a different sentence structure, and then add an in-text citation in the correct format (e.g. Boyd and Tucker, 1998); this gives credit to the original author while demonstrating that you have understood and can communicate the idea independently;

(2) direct quotation with citation: when the exact wording of the original author is important and cannot be paraphrased without losing meaning, copy the exact words and enclose them in quotation marks, followed by the in-text citation including the page number; direct quotation should be used sparingly and only when the precise wording is essential.

5. Any five career pathways: (1) fisheries officer in the Federal Department of Fisheries or a state fisheries department (fish stock assessment, licensing, enforcement, extension services to fishing communities); (2) research scientist at NIFFR, NIOMR, or a university department (conducting and publishing research on aquaculture productivity, fish biology, or fisheries management); (3) commercial catfish farmer or fish farm manager (owning or managing a catfish grow-out or hatchery operation as a private business); (4) aquaculture input supplier (dealing in catfish feed, fingerlings, pond equipment, water quality testing kits, and other inputs needed by fish farmers); (5) fish processor and exporter (buying farmed or captured fish, processing (smoking, freezing, portioning), and distributing domestically or exporting to international markets including the Nigerian diaspora); (6) environmental officer with NESREA or NOSDRA (monitoring and enforcing environmental regulations affecting aquatic ecosystems); (7) aquaculture or fisheries consultant (providing technical advisory services to investors, government, NGOs, and international organisations); (8) academic researcher pursuing MSc and PhD leading to a university teaching and research career.

References and Attributions [Series 5]

Textual References (Books and External Sources)



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

Figures, Plates, Tables, and Boxes

1. Figure 5.1: Bar chart comparing catfish growth at three dietary protein levels Attribution: AI generated. Suggested OER search string: "catfish growth bar chart protein level ANOVA significance letters OER research".
2. Table 5.1: Alternative protein sources for catfish and tilapia feeds Attribution: AI generated. Suggested OER search string: "alternative protein sources aquaculture catfish Nigeria fishmeal soyabean black soldier fly OER table".
3. Figure 5.2: Integrated catfish-poultry-vegetable farm nutrient flows Attribution: AI generated. Suggested OER search string: "integrated fish poultry vegetable farm Nigeria nutrient flow diagram OER".
4. Box 5.1: Climate change impacts and adaptation strategies for Nigerian fisheries Attribution: AI generated. Suggested OER search string: "climate change Nigerian fisheries aquaculture impacts adaptation strategies OER box".
5. Box 5.2: Career pathways for Nigerian fisheries graduates Attribution: AI generated. Suggested OER search string: "Nigerian fisheries aquaculture graduate career pathways public private international OER box".

