CLIMATE SMART ACTIONS (CSA) AQUACULTURE, AGROFORESTRY AND RESOURCES MANAGEMENT

GLOBAL ISSUES & LOCAL PERSPECTIVES

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Preface

This book adopts an exegetical approach as well as a pedagogic model, making it attractive agriculture and environmental economics teachers, professional practitioners and scholars. It is eschews pedantry and lays bars the issues in such clarity that conduces to learning. The book elaborates on contemporaneous **Climate smart actions (CSA) aquaculture, agroforestry and resources management** issues of global significance and at the same time, is mindful of local or national perspectives making it appealing both to international and national interests. The book explores the ways in which **Climate smart actions (CSA) aquaculture, agroforestry and resources management** issues are and should be presented to increase the public's stock of knowledge, increase awareness about burning issues and empower the scholars and public to engage in the participatory dialogue **Climate smart actions (CSA) aquaculture, agroforestry and resources management** necessary in policy making process that will stimulate increase in food production and environmental sustainability. **Climate smart actions (CSA) aquaculture, agroforestry and resources management :** *Global Issues & Local Perspectives* is organized in three parts. Part One deals with The Concept of **Climate smart actions (CSA)**, Part Two is concerned with The Concept of **aquaculture,** and Part Three deals with the Concept of **agroforestry and resources management**

Eteyen Nyong; March 2026

Chapter 9:

Climate Smart Aquaculture

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ACRONYMS

FAO:	Food and Agriculture Organization
RAS:	Recirculating Aquaculture Systems
TBP:	Tank-By-Pond
AFT:	Aqua Flow Through
NF:	Natural Feeds
DF:	Dry Feeds
MF:	Moist Feeds
WF:	Wet Feeds
LF:	Larval Feed
SF:	Sinking Feed
FF:	Floating Feed
BCR:	Cost-Benefit Ratio
CBA:	Cost-Benefit Analysis
CVP:	Cost-Volume-Profit
ABC:	Activity-Based Costing

1.1 Introduction

Aquaculture is the controlled cultivation of aquatic organisms like fish, shellfish, algae, and plants for various purposes, including food production, recreation, and scientific research in ponds, tanks, or pens (FAO, 2024). Amundson and Andres (2025) define aquaculture as the science and practice of breeding, rearing, and harvesting fish, crustaceans, mollusks, and aquatic plants under controlled conditions for food, income, and conservation purposes. El-Sayed (2025) described aquaculture is the cultivation of aquatic organisms in freshwater, brackish water, or marine environments to enhance production through feeding, stocking and protection from predators. As capture fisheries continue to decline due to overfishing, pollution, and climate change, aquaculture has emerged as a vital alternative for meeting the increasing global demand for animal protein and ensuring food security. In many developing countries, particularly in Nigeria, aquaculture plays a significant role in livelihoods, employment generation, and rural development. Modern aquaculture integrates scientific principles of biology, water quality management, nutrition, and health management to achieve sustainable and profitable production. This chapter introduces the concept of aquaculture, importance andmajor production systems, highlights; the role of aquaculture in sustainable agriculture, environmental conservation, national development, opportunities and challenges associated with aquaculture in contemporary agricultural systems.

1.1 Importance of Aquaculture

Al-Saleh (2025) reported that aquaculture provides a sustainable source of protein, nutrients for a growing global population, boosts; local economies, food security and conservation of wild species.

a. Food security and nutrition: Aquaculture provides protein, vitamins, and omega-3 fatty acids, improves food availability and access, reducing vulnerability to natural crashes in wild fisheries.

b. Economic development: It generates employment and income in rural areas alleviating poverty and source foreign exchange through exports.

c. Environmental sustainability: Aquaculture is used for conservation of threatened or endangered species and rebuilding of wild stocks.

d. Diversification: It diversifies farming practices and creating new income opportunities for farmers.

1.2 Aquaculture Production

According to Adebayo *et al.* (2025), aquaculture production is categorized by the water type as fresh, marine, or brackish and by system as ponds, cages or recirculating systems. Production can also be classified as extensive, semi-intensive, or intensive. The major systems include broodstock, seed production, and grow-out phases.

I.2.1 Types by water environment

Adebayo *et al.* (2025) reiterated that aquaculture, the farming of aquatic organisms in controlled environments, is primarily classified into three types based on the water environment's salinity: freshwater, marine (saltwater), and brackish water. The choice of environment largely depends on the species being farmed, local conditions, and available resources, all of which influence the specific systems and intensity of the operation.

a. Freshwater Aquaculture: This type occurs in inland water bodies such as ponds, rivers, lakes, and man-made tanks on land. It is the most common form globally and accounts for the majority of farmed fish production. Common species: Carp, catfish, trout, and tilapia are widely cultivated in freshwater systems. Systems used: Ponds (static water), raceways (flow-through channels), and land-based Recirculating Aquaculture Systems (RAS) are common methods.

b. Marine Aquaculture (Mariculture): This refers to the cultivation of marine organisms in saltwater environments, including the open ocean, coastal areas, and specialized tanks or ponds filled with seawater. Common species: Finfish like salmon, seabass, and tuna, as well as shellfish (oysters, clams, mussels, shrimp), and seaweed are prominent in mariculture. Systems used: Methods include floating net pens/cages in the open water, on-bottom culture (seeding the seafloor), and longlines suspended from rafts.

c. Brackish Water Aquaculture: This type takes place in estuaries and coastal areas where freshwater and saltwater mix, resulting in an intermediate salinity level (typically between 0.5 and 30 ppt). Common species: Species that can tolerate a range of salinities, such as certain types of shrimp and specific fish like milkfish and mullet, are farmed in these areas. Systems used: Both ponds and cages are used, with management practices ranging from extensive to intensive depending on the species and location.

Figure1: Fresh water Aquaculture Figure 2: Brackish Aquaculture Marine Aquaculture

1.2.2 Types by System and Intensity

According to Sabastian *et al. (*2024), aquaculture production by intensity classifies farming systems from extensive to intensive, with semi-intensive systems in the middle, differing in stocking density, feeding, fertilization, water management, and technology. Extensive relies on natural productivity, semi-intensive uses some natural food plus fertilizers/supplemental feed and intensive uses high densities, formulated feeds, advanced technology, and complete control .

1. Extensive Aquaculture: Low density with inputs reling heavily on natural productivity; minimal intervention, sometimes fertilization. Examples are rice-fish systems and large ponds with minimal feeding.
2. Semi-Intensive Aquaculture: Medium density with combined input from natural productivity with supplemental feeding and/or fertilization; medium level of stock management. Example is pond farming with some formulated feed.
3. Intensive Aquaculture: High density with high stocking, formulated feeds, full water quality control (oxygen, waste), disease control, often closed systems (RAS) or cages. Examples are Recirculating Aquaculture Systems (RAS), net cages in open water.

Figure 4: Entensive Aquaculture   Figure 5: Intensive Aquaculture   Figure 6: Semi-Intensive

1.2.3 Phases of Aquaculture Production

Khanom *et al.* (2023) described the phases of aquaculture production as broodstock, aqua seed production and aqua grow out systems

1. Broodstock system is a managed environment (ponds, tanks) holding sexually mature aquatic animals (fish, shellfish) specifically for controlled breeding to produce eggs or young for aquaculture, conservation, or restocking, involving careful control of water quality, diet, and spawning cues to maximize healthy offspring. These systems ensure a consistent, high-quality supply of juveniles (seed stock) for farming or stocking, often using selective breeding for desirable traits.

   a. Key components and functions

      a) Reproductively Mature Adults: The core of the system are the broodfish, healthy, mature individuals selected for breeding.

      b) Controlled Environment: Tanks or ponds mimic ideal natural conditions, with controlled temperature, light (photoperiod), and water quality (pH, aeration) to stimulate spawning.

      c) Conditioning: Animals receive specialized diets and stimuli to promote gonadal development and high egg/sperm production (fecundity).

      d) Hatchery Integration: Eggs or sperm are collected, fertilized, and hatched to produce larvae or fry, which are then grown out.

      e) Genetic Management: Systems maintain specific genetic lines (strains) for disease resistance, growth, or conservation, often improving stock through selective breeding.

   b. Applications

      a) Aquaculture: To provide consistent seed stock for commercial fish farms.

      b) Conservation: To support endangered species recovery and habitat restoration.

      c) Fisheries Management: To produce fish for recreational fishing and mitigate habitat loss.

2. Aqua seed production is the process of cultivating and generating the initial life stages (eggs, larvae, fry, fingerlings, post-larvae, or plantlets) of aquatic organisms under controlled or semi-natural conditions for use in aquaculture. This process is a critical part of the aquaculture production cycle, ensuring a reliable and consistent supply of healthy, high-quality stock for grow-out farms.

   a. Key aspects of aqua seed production

      a) Organisms: It involves a wide variety of species, including finfish (carp, salmon, tilapia, catfish, sea bass), crustaceans (shrimp, prawns, lobsters, crabs), molluscs (oysters, mussels, clams), and aquatic plants/algae (seaweed).

b) Methods: Seed is obtained through various methods ranging from collection from the wild to highly controlled hatchery production.

c) Natural Spawning: This occurs in ponds or tanks by simulating natural environmental conditions like water temperature changes or the rainy season.

d) Induced Spawning: Hormones (e.g., pituitary gland extract, synthetic hormones) are injected into mature broodstock to induce final maturation and spawning, especially for species that do not spawn readily in captivity.

e) Artificial Spawning: Eggs and sperm are manually extracted and mixed for fertilization, often followed by incubation in specialized jars or troughs.

b. Process include:

i. Broodstock Management: Maintaining healthy, mature parent stock with desirable genetic traits (fast growth, disease resistance).

ii. Hatchery/Incubation: Facilitating the hatching of eggs and initial development of larvae, often in specialized tanks with controlled water quality, temperature, and aeration.

iii. Larval Rearing/Nursery: Feeding and raising the young organisms (e.g., larvae fed live feeds like rotifers and Artemia, or fish fry fed artificial diets) until they reach a suitable size (fingerlings or post-larvae) for transfer to grow-out facilities.

c. Importance challenge

i. A stable supply of quality seed is essential for the sustainable expansion of the aquaculture industry, reducing pressure on wild fish populations and meeting the growing global demand for seafood.

ii. Major challenges in aqua seed production include maintaining good water quality,

iii. controlling diseases during vulnerable larval stages, ensuring high-quality broodstock genetics (to avoid inbreeding), and having access to skilled technical expertise.

3. Aqua grow out refers to raising fingerlings from juvenile stages to sellable weight, using various systems like ponds, cages, or RAS (Recirculating Aquaculture Systems).

a) Key Aspects of Aqua Grow Out

i. Systems: Ponds (earthen), Cages (in large water bodies), Flow-through (raceways), or Recirculating Aquaculture Systems (RAS) for land-based tanks.

ii. Management: Involves detailed feeding strategies, stocking density, health monitoring and environmental control.

iii. Goal: To efficiently grow aquatic animals from fingerling to harvest size to optimize profit..

iv. Technology: Software help in tracking everything from water quality to inventory.



Figure 7: Broodstock   Figure 8: Aqua weeds   Figure 9 Grow-out

1.3 Aqua Ponds

According to Hemal *et al.* (2024), aqua ponds generally refer to freshwater ponds used for fish farming. They require proper construction, water quality management, and suitable aquatic plants to thrive.

a. Commercial Aquaculture: Large ponds for raising fish using FAO techniques for intensification.

b. Mobile Ponds: Portable, often fabric-lined ponds (e.g., Dickem Aquatech) for flexible fish farming.

c. Garden/Backyard Ponds: Smaller decorative ponds featuring water features, plants, and fish.

d. Tank-By-Pond (TBP): Intensive fish farming within existing ponds using tanks and aeration.


Figure 10: Concrete pond   Figure 11: Plastic pond   Figure 12: Earthen pond

1.3.1 Key considerations for ponds

Hemal *et al.* (2024) enumerated the key considerations for ponds as:

CLIMATE SMART ACTIONS (CSA) AQUACULTURE, AGROFORESTRY AND RESOURCES MANAGEMENT-- ISBN 978-978-60709-1-6

a) Construction: Proper design for water flow, depth, and fish management is crucial.

b) Plants: Choose appropriate aquatic plants for controlling invasive species, and adding oxygen.

c) Water Quality: Requires filtration, aeration, and monitoring when cycling biological filters.

d) Technology: Aeration, filtration, and specialized systems to boost productivity and sustainability.

1.4 Aqua Cage

Baluku *et al.* (2025) viewed aqua cage as an enclosed mesh structure allowing water to flow freely, providing oxygen and removing waste, while the fish inside are contained for controlled feeding, monitoring, and harvesting.Aquatic organisms are raised in a defined space with feed and protection from predators. Cages consist of a durable frames and a net bag that holds the fish. They float using pontoons or other buoyancy devices.

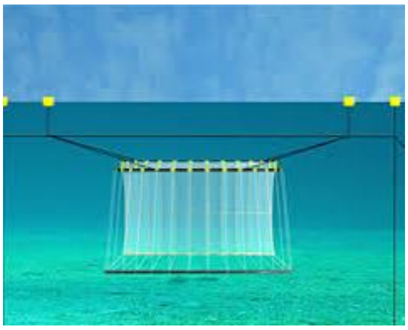
1.4.1 Types of Cage

Baluku *et al.* (2025) enumetrated that a variety of cages were designed to suit different environments and species. These include:

i. Floating Cages: The most common type, floating on the surface and anchored to the seabed.

ii. Submerged Cages: Lowered below the water surface to avoid storms, strong currents, or parasites.

iii. Fixed Cages: Used in shallower waters, supported by posts driven into the substrate.



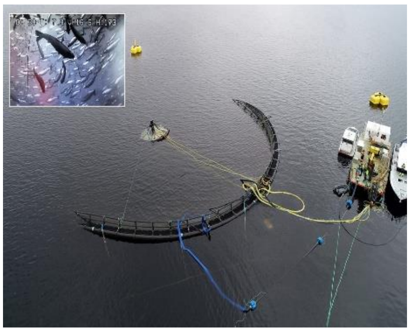


Figure 13: Floating cage Figure 14: fixed cage Figure15: Submerged cage

1.4.2 Advantages of Cage

Baluku *et al.* (2025) advanced that cages:

a. Offer high production yields,

b. Have relatively low initial infrastructure costs compared to land-based systems and

c. Flexibility to use existing water resources that might not otherwise be suitable for farming.

1.5.3 Environmental Considerations for Cages

Baluku *et al.* (2025) said while efficient, cage culture has environmental impacts such as:

a) Accumulation of waste,

b) Spreading of disease and

c) The risk fish escaping into the natural environment.

1.5 Aqua Flow Through

Kim and Jin (2024) posited that aqua flow through refers to method for raising fish, managing rain runoff and water-saving techniques. Raw water enters, oxygenates the tank, carries waste out, and then leaves the system, providing natural conditions. Biologically safe, simple, and ideal where water quality is stable. Systems like AquaFLOW collect stormwater in a pump well, and when levels rise, pumps move it for treatment or council systems, preventing overflows. Offers smart valves that compress air and regulate flow/pressure reducing water bills and waste without affecting performance.

1.6 Recirculating Aquaculture System (RAS)

Sadeeq (2025) described the recirculating Aquaculture System (RAS) as specialized mechanical and

biological filters, oxygenation, and disinfection used to remove waste and maintain optimal water quality, allowing for high-density fish production with minimal environmental impact and water use. Reuses 90% or more of the water, drastically reducing fresh water needs. Can be set up almost anywhere reducing transport. Prevents escapees, limits disease/parasite spread, reduces antibiotic use, and minimizes impact on natural waters. Stable conditions lead to reduced stress, better fish health, and predictable growth. Enables intensive, high-density farming.

1.7 Aquaculture Site Selection

Mzoughi *et al.* (2025) opinned that aquaculture site selection involves evaluating ecological, biological, social, economic, and legal factors. Considerations include water supply, quality, quantity, and source; soil quality and topography; legal regulations and land ownership; accessibility for transportation, and proximity to markets.

a. Ecological and biological factors are based on water supply, assess to the source, quantity, soil and topography, salinity, currents, wave climate, and wind patterns.

b. Social and economic factors hinges on good access for transportation, amenities, skilled workforce, technical guidance, local culture, traditions, and acceptance from the community.

c. Legal and regulatory factors deals with compliance with all national and local environmental regulations, land ownership, accepting environmental regulatory procedures.

d. Other considerations depend on species being cultured, type of production system, reliable source for seeds, fingerlings and feed for the cultured species.

1.8 Aquaculture Nutrition

According to Hassan (2025), aquaculture nutrition involves providing balanced diets meeting specific needs of different aquatic species for growth, health, and reproduction. Feeding strategies range from using natural food sources, fertilization, formulated feeds and additives to enhance digestibility, health, and sustainability.

a. Aquaculture protein requirements optimal level is influenced by species level, water salinity, and rearing temperature. Lipids transfer energy from lower trophic levels (like phytoplankton) to higher ones (fish and eventually humans).

b. Aquaculture carbohydrate requirements levels are important because it provide energy and

stability to feed pellets, while high-carb diets can impact growth and immunity if the species cannot digest them efficiently. The type of carbohydrate and the water temperature influences digestibility.

c. Aqua micronutrients are essential mineral elements required for the healthy growth and function of aquatic life. These nutrients are vital for chlorophyll formation, protein synthesis, and regulation of metabolism. Deficiencies can lead to stunted growth, poor health and disease.

d. Aqua feed additives are beneficial substances added in fish and shrimp feed to improve nutrient utilization, boost immunity and enhance growth. These include probiotics, enzymes, antioxidants, immunostimulants, binders and pigments.

1.9 Aquaculture Feed and Feeding Methods

Zuberu *et al.* (2024) and Tewari *et al.* (2025) agreed that aquaculture feeds are categorized as natural or artificial, with artificial feeds further divided by moisture content and form. They are classified as sink or float, or by their ingredients, which include plant-based and animal-based protein sources. Specialized feeds like those for larvae, medicated feeds, and pigment-enhanced feeds are also used.

a) Natural feeds are naturally available, such as plankton, aquatic plants and detritus.

b) Artificial feeds are commercially prepared and balanced for nutrition.

c) Dry feeds contain 7-13% moisture and are easy to store and transport such as pellets and flakes.

d) Moist feeds contain 25-45% moisture. They are easier to transport than wet feeds.

e) Wet feeds contain 45-70% moisture. They are often made from ingredients like fish waste.

f) Larval feed for young fish and shrimp including micro-coated, and spray-dried.

g) Sinking feed sink to the bottom, ideal for bottom-feeding fish and monitoring is not easy.

h) Floating feed stays on the water's surface for farmers to observe feeding habits and prevent waste.

i) Plant-based ingredients include cereals, oilseed meals and bran and cassava.

j) Animal-based ingredients are by-products from animal sources such fish meal and meat meal

1.9.1 Aquaculture Feeding Methods

Parry *et al.* (2025) said aquaculture feeding methods include hand-feeding using feed trays, demand

Feeders, automatic blowers, floating frames and submerged trays. The choice of method depends on species being, size of the operation and the desired cost and labor efficiency.

a) Manual and semi-manual feeding involves broadcasting feed by hand, using perforated baskets filled with moist feed nibbled by the fish good for smaller fish and helps reduce waste.

a) Semi-automated feeding using demand feeders triggered by the fish, releasing feed on demand. They are cost-and labor-efficient but require a maximum feeder-to-fish ratio.

b) Automatic feeders powered by electricity and are designed to provide a consistent feeding regimen, ensuring fish receive a steady supply of food.

c) Automatic blowers broadcast feed over a large area. While efficient, they require electricity, can be expensive.

d) Timer-based feeders: These can use mechanisms like an endless screw or a rotating disc to dispense feed at set intervals.

Figure 16: Manual feeding   Figure 17: Semi-automated   Figure 18: Automated

1.9.2 Feed Storage and supply

Ja'afar (2025) and Farouq (2025) recommended that feeds must be stored appropriately to maintain quality. For large-scale operations, this involves storing feed in silos for automatic or pneumatic systems, while smaller farms might store feed in its original packaging. Feeds are supplied in various ways, including 20kg bags, big bags, or bulk delivery by truck.

1.10 Aquaculture Species

According to Ciriminna *et al.* (2024) and Laining *et al.* (2025), aquaculture species include a wide variety of aquatic organisms such as finfish, shellfish, and plants. Common examples are tilapia, salmon, and catfish for fish; shrimp, oysters, and mussels for shellfish; and seaweeds and water chestnuts for plants. The choice of species depends on the farming method and the environment (Khalid *et al.,* 2025).

a. Aqua Tilapia: Refers to tilapia fish produced in controlled aquatic environments highly efficient due to the fish's rapid growth, high protein content, and hardiness, making tilapia known as the aquatic chicken. They are fraised in small ponds to large commercial operations, a source of protein.

b. Salmon are a rich source of protein and omega-3 fatty acids, with both wild and farmed options available, and are known for their health benefits and culinary versatility. Salmon are classified into genus Salmo in the Atlantic and genus Oncorhynchus in the Pacific.

c. Aqua trout are rich in vitamin B and minerals raised in controlled environments for commercial purposes. Highlights the modern, technological and sustainable approach to aqua farming and marketing.

d. Aqua catfish refers to a type of freshwater or saltwater aquarium catfish or aquaculture catfish feed. A source of high quality animal protein, omega-3 fatty acid and phoshorus. Examples include Pictus catfish, Clarias gariepinus and Channel catfish.

e. Aqua carp are a globally important aquaculture species, with the common carp Cyprinuscarpio being a key example. They are farmed for food, hardy and well-suited to various farming conditions, making them a sustainable and efficient source of protein.

f. Shrimp are active scavengers, keeping tanks cleaner, come in vibrant colors, adding visual interest and help maintain a clean aquarium by eating detritus and algae.

g. An oyster is a saltwater bivalve mollusk and plays crucial role in filtering and cleaning ocean waters, forming vital reef habitats that protect coastlines and provide rich nutrition.

h. Mussels are are known for their vital role in ecosystems as natural water filters, removing algae, bacteria, and pollutants from the water, which helps keep the water clean and clear.

i. Clams are filter feeders. They help filter the water, improving water quality and species diversity by extracting tiny particles of plankton and organic material.

j. Crayfish are freshwater crustaceans requiring proper habitat to prevent burrowing damage or invasiveness. Nigerian crayfish has rich umami flavor in soups and stews.

k. Aqua algae and sea weed form the base of the food chain and nutrients. Excessive algae growth is a symptom of underlying problem to be addressed.

l. Water chestnuts can refer to the edible, crisp corm from Eleocharis dulcis (a grass) or the invasive aquatic plant Trapa natans (water caltrop), known for its spiny.. The edible one is a vegetable used in Asian cooking, whereas the invasive Trapa natans is a problematic weed in North America.

Fugure 19: Salmon Fugure 20: Trout Fugure 21: Carp

Figure 22: Aqua mussels Figure 23: Aqua crimps Figure 24: Aqua oyster

1.11 Aquaculture Management

Haque *et al.* (2024); Abdel-hardy *et al.* (2024) and Kose (2025) confirmed that aquaculture management involves pond preparation and stocking, water quality management, and fish health and feeding, which together aim to ensure sustainable production. Key activities involve preparing culture units, stocking with appropriate species and densities, and maintaining high-quality water through measures. Pond and system preparation

a. Choose a suitable location and prepare the culture unit by draining, drying, and cleaning it to remove organic residue and improve soil properties. Impound the pond with good quality water supply and use a combination of organic and inorganic fertilizers to promote a natural food source.

b. Stock fingerlings or juveniles of the same species and size to prevent competition and ensure uniform growth. Avoid overcrowding by controlling the stocking rate to prevent stress and disease outbreaks.

c. Feeding and nutrition :Provide a high-quality diet that meets the nutritional needs of the species being farmed. Feed the fish appropriately, remove uneaten or uneaten food, and ensure proper storage of feeds. Monitor feeding behavior for early signs of stress or disease.

d. Health and biosecurity: Establish a disease surveillance and diagnostic program, maintain effective biosecurity measures, watch for abnormal behavior caused by stress or disease. Protect the fish from predators by using fences or other methods.

e. Environmental management and sustainability: Promptly remove dead or sick animals and other debris from the culture unit to maintain water quality. Avoid unnecessary handling and other stressors that can compromise fish health.

1.12 Aquaculture Fish Quality Control

Zuhaer *et al.* (2025); Aubakirova and Alikulov (2025) and Issa-Zacharia *et al.* (2025) confirmed that aquaculture fish quality control involves maintaining optimal water quality, using biosecurity measures and hygiene standards throughout handling, sensory evaluation and objective testing to verify the fish is fresh and safe for consumption.

a. Environmental and production controls: Involves water quality monitoring, biosecurity and contamination prevention, equipment and facility maintenance and proper storage to keep harvested fish properly chilled and out of direct sunlight to prevent spoilage.

b. Handling and processing hygiene: Comprises personal hygiene to enforce strict personal hygiene rules, sanitation to regularly clean and sanitize all surfaces that come into contact with the fish, and waste disposal to make sure all waste is disposed of in a sanitary manner.

c. Freshness and safety assessment: Sensory evaluation is the regular inspection of the fish for freshness, instrumental testing to conduct bacteriological tests to verify microbial safety and temperature control to prevent spoilage.

d. Traceability and quality assurance: Traceability to maintain complete records throughout the production cycle to ensure traceability from farm to consumer. Quality assurance programs to address product specifications, raw material inspection, process control, and personnel training. Compliance to adhere to international and local quality and safety standards and regulations.

1.13 Aquaculture Diseases

Mahmud *et al.* (2025); Tayyab *et al.* (2025) and Khan *et al.* (2025) pointed out that aquaculture diseases are illnesses affecting farmed aquatic animals caused mainly by viruses, bacteria, fungi, parasites, or poor environmental conditions, leading to significant economic losses through high mortality and reduced growth. Common examples include Vibriosis, viral outbreaks, parasitic infections and fungal problems, often exacerbated by stress from overcrowding, poor water quality, and inadequate nutrition.

a) Causes Pathogens consisting of viruses, bacteria, fungi, and protozoan/metazoan parasites. Environmental stress due to Poor water quality, overcrowding, and inadequate feed. Management practices stress from handling, transportation, or introduction of infected stock.

  a. Common disease types are bacterial such as vibriosis, streptococcosis, columnaris and bacterial kidney disease. Viral diseases that are Infectious suchas Salmon Anemia (ISA), Viral Hemorrhagic Septicemia (VHSV), Betanodavirus (Viral Nervous Necrosis). Parasitic diseases consisting of sea lice and amyloodinium. Fungal diseases such as saprolegniasis.

  b. Impact: High mortality rates, sometimes 100% loss of a batch. Reduced growth, poor feed conversion, and damaged product quality. Major economic burden on the aquaculture industry. Prevention and control. Good husbandry to maintain excellent water quality, provide quality feed, avoid overfeeding. Biosecurity to quarantine new stock, control movement of people and equipment, disinfect facilities. Vaccination and therapeutics by using approved vaccines and treatments. Monitoring regular health checks and disease surveillance.

1.13.1 Aqua disease prevention and control

Üstündağ (2025); Yue and Guo (2025); Alfatat *et al.* (2025) and Sanjay (2024) reported that aqua

disease prevention and control involves a combination of strong biosecurity, sanitation, and management practices to maintain water quality and minimize stress on fish. Prevention includes regular disinfection of equipment and facilities, quarantining new fish, and maintaining high-quality water. For control, immediate removal of dead fish and treating infected ponds and fish are key steps.

1) Prevention and biosecurity is to routinely disinfect all equipment like nets and buckets that come into contact with water, and implement strict hygiene for workers. Disinfect facilities between stocking cycles. Quarantine to isolate new or returning fish in a separate holding area to prevent introducing diseases to your main stock. Water quality to maintain good water quality through regular monitoring and treatment. Some treatments like adding lime can improve water quality and prevent disease. Reduce stress in handling, stocking and grading. Feed management to provide appropriate and high-quality feed, and consider reducing the feeding amount during a disease outbreak. Egg disinfectionto prevent the vertical transmission of certain diseases from parent to offspring.

2) Control and treatment: Remove dead and sick fish immediately and dispose them properly to prevent further spread of disease. Disinfect equipment by thoroughly using solutions like formaldehyde, chlorinated lime, or potassium permanganate. Treat the pond in case of disease breaks out, specific chemicals can be sprayed into the pond. Treat the fish through methods like oral administration with medicated feed or external application of treatments like a 1 ppm solution of bleaching powder or a 2

ppm solution of Chinese gall spray into the pond. Isolate sick fish to a separate, treated area if possible. Conduct regular lab analyses to monitor fish health and identify pathogens early, as mentioned by

1.14 Aquaculture Post-Harvest

Kyule *et al.* (2025); Yadav *et al.* (2025) and Ejeta *et al.* (2024) viewed aquaculture post-harvest as the activities after harvesting fish and shellfish comprising sorting, cleaning, processing, cooling and packaging, to maintain product quality and marketability. These practices are crucial for minimizing spoilage and maximizing the value of the harvest by ensuring food safety and extending shelf life. Proper post-harvest handling minimizes economic losses and ensures that consumers receive a high-quality product.

1. Key post-harvest activities: Harvesting and handling fish with minimal stress and damage, especially crucial in high-temperature environments to slow down spoilage. Sorting and grading harvested products based on size, species, or quality to meet different market requirements. Rapidly chilling harvested products, ideally with ice or through other cooling methods, to slow down bacterial growth and enzymatic activity that causes spoilage. Processing fish by smoking, drying, salting, freezing, and fermentation to preserve the product and extend its shelf life. Properly packaging products to protect them and labeling them with necessary information, such as species and date. Storing products in temperature-controlled environments to maintain quality.
2. Importance of post-harvest management: Reduces losses by proper handling to prevent post-harvest fish losses, spoilage and inadequate storage. Maximizes value of products to fetch higher prices in the market. Ensures food safety practices to help prevent contamination and ensure the safety of the final product for consumers. Enhances consumer satisfaction by providing them with high quality, fresh, and safe products meeting their expectations. Contributes to food security by reducing losses, making more fish becomes available for consumption.

1.14.1 Fish Harvesting Equipment

Chandravanshi *et al.* (2025) and Siddiqui *et al.* (2024) observed that fish harvesting equipment includes nets, traps, lines, mechanical gear and smaller tools like scoop nets, used to capture fish from wild fisheries or aquaculture farms for various purposes like collection, transport, and sale, ranging from simple manual tools to complex automated systems.

1.14.2 Types of harvesting equipment

According to Mohammed *et al.* (2025), types of aqua harvesting equipment are:

a. Seine are long nets with floats and weights, used to encircle fish in ponds or open water.

b. Gillnets a wall of netting that entangle fish by their gills as they try to swim through.

c. Cast nets are weighted, circular nets thrown by hand to spread out and sink, trapping fish.

d. Dip/scoop are handheld nets for catching individual fish or smaller quantities, common in fish farms.

e. Traps and pots are enclosed devices that fish enter but struggle to exit, often used with bait.

f. Hook-and-line (rod/reel), trolling and longlines. Trawls are conical nets dragged by boats (trawlers).

g. Dredges are metal frames with nets or teeth dragged along the seabed to collect shellfish.

h. Fish pumps move large quantities of fish with minimal stress.

i. Traditional tools consist of stake nets, Chinese dip nets, trammel nets, woven baskets, and manual mud rakes for pond maintenance.

j. Purpose: These tools help farmers and fishers collect fish for market, move them between ponds grade, transport them, or simply assess growth in a controlled environment.

Figure 25: Aqua siener Figure 26: Aqua trawl Figure 27: Fishing net

1.15 Fish Preservation

Venkatappa *et al.* (2025); Kurek *et al.* (2024) and Chand (2024) reiterated that to preserve fish, you can chill it on ice for short-term freshness, freeze it (vacuum-sealed is best) for months, or use traditional methods like salting, drying, and smoking to remove moisture and prevent spoilage for longer, unrefrigerated storage. For immediate needs, wrapping in damp towels or using ice packs in a cooler works well.

a. Refrigeration: Pack whole fish on ice, or seal fillets in bags andcontainers covered in ice.

b. Cooler/Ice Packs: For travel or a few days, store fish in a cooler with ice or ice packs.

c. Damp Towels: Wrap fish in damp paper towels to maintain moisture before refrigeratin

d. Drying: Cut fish into strips and hang to air dry in the sun and wind until dehydrated.

e. Salting: Cover cleaned fish with sea salt to draw out moisture, drain, rinse before storing.

f. Smoking: A process using smoke to preserve fish, dry, for extended shelf life and flavor.

g. Pickling: Soak fish in brine, pack vinegar solution with spices for an acidic, preserved product.

h. Preparation: Gut and clean fish as soon as possible.

i. Temperature: Keep fish as cold as possible, ideally near freezing (32°F/0°C) for chilling.

j. Packaging: Use airtight, moisture-vapor-resistant packaging for freezing to prevent freezer burn.

Figure 28: Fish drier
Figure 29: fish pickling
Figure 30: Fish packaging

1.16 Aquaculture Record Keeping

According to Le *et al.* (2025) Ekesa (2024), aquaculture record keeping involves systematically recording all farm activities to aid in financial management, production analysis, and future planning. Key records include stocking details, feed usage, water quality monitoring, health and disease logs, and financial transactions such as income and expenses. These records can be kept in physical notebooks or digital spreadsheets and are essential for tracking performance, controlling costs, and securing funding.

a. Types of records
   a) Stocking: Dates, species, source, quantity, and cost of seed/fingerlings
   b) Growth: Growth rates, weight at different stages, and survival rates
   c) Harvesting: Dates, quantities harvested, and sales data (price per unit, revenue)
   d) Yield: Yield per unit area or volume

b. Operational records
   1) Feed: Types, quantities, schedules, and feeding methods used
   2) Water quality: Regular measurements of temperature, pH, dissolved oxygen, ammonia, etc.
   3) Health: Disease outbreaks, parasite occurrences, and treatments administered
   4) Environmental: Weather conditions, water source details, and waste management practices
   5) Equipment: Inventory, maintenance, and repair schedules

c. Financial records
   i. Income: All sales and revenue, including both cash and credit
   ii. Expenditures: Costs for seed, feed, chemicals, labor, and maintenance
   iii. Profitability: Calculations to determine profit or loss

d. Methods of record keeping
   1. Paper: Use notebooks, ledgers, or a "shoebox" method for physical documents
   2. Digital: Use spreadsheets (e.g., Google Sheets, Excel) or specialized software programs

e. Importance of record keeping
   a) Profitability: Helps in evaluating the financial success of the farm
   b) Management: Provides data for informed decision-making, future planning, and improvements
   c) Financial support: Creates a strong case for securing loans or credit from financial institutions
   d) Cost control: Identifies areas where expenses can be reduced
   e) Performance evaluation: Allows for assessment of management skills and farm value

1.17 Cost-Benefit Ratio (BCR)

In their studies Zanna and Musa (2025) El-Sayed (2025) contributed that cost analysis is the systematic process of identifying, measuring, and evaluating all costs associated with a project, product, or business operation to support informed decision-making, improve efficiency, and determine profitability, often involving comparing costs to benefits (cost-benefit analysis) or breaking down expenses into direct/indirect, fixed/variable components for strategic planning and resource allocation. It helps businesses understand resource use, optimize spending, and assess financial viability.

1. Key Aspects of Cost Analysis
   a. Identification and Classification: Pinpointing and categorizing costs (e.g., direct labor, raw materials, utilities, rent) into types like fixed, variable, or semi-variable.
   b. Cost-Benefit Analysis (CBA): Comparing total costs against total benefits (profits, savings, value) to see if an investment is worthwhile, often expressed through metrics like BCR.
   c. Cost-Volume-Profit (CVP) Analysis: Understanding how changes in volume affect costs and profits, including calculating break-even points.

d. Activity-Based Costing (ABC): Assigning costs to specific activities to get of their true cost.

e. Strategic Decision Making: Using cost data to set prices, control spending, justify investments, and improve overall operational efficiency.

2. Cost Analysis Importance

a) Informed Choices: Makes decisions data-driven rather than based on guesswork.
b) Profitability: Helps maximize profits by finding areas to reduce costs or increase value.
c) Resource Allocation: Guides where to best invest time, money, and resources.
d) Performance Evaluation: Allows comparison of actual costs to budgeted costs for improvement.

1.18 Aquaculture Problems

Adebayo *et al.* (2025); Sonja *et al.* (2025) and Sebastian*et al.* (2024) stressed that aquaculture faces major problems like environmental damage (pollution, habitat loss, algal blooms), disease outbreaks in dense populations, high costs (feed, labor, tech), lack of trained staff/extension, and regulatory gaps, leading to issues like chemical/antibiotic pollution, escaped fish affecting wild stocks, and food safety concerns for consumers from contaminants in farmed fish, all while struggling with infrastructure and access to capital.

a. Environmental Issues

a) Water Pollution: Effluents rich in nutrients (nitrogen, phosphorus) and chemicals (antibiotics, pesticides) cause eutrophication, algal blooms, and oxygen depletion.

b) Habitat Destruction: Clearing mangroves or altering coastlines for farms destroys natural habitats.

c) Wild Fish Impact: Escaped farmed fish can interbreed with wild populations, and parasites/diseases (like sea lice) can spread from farms to wild fish.

b. Economic and Operational Challenges

1) High Costs: Expensive feed, labor, transportation, and technology are major hurdles.

2) Inadequate Infrastructure: Poor roads, storage, and water supply hinder operations.

3) Lack of Skilled Personnel: Shortage of trained managers, technicians, and effective extension services.

c. Biological and Health Concerns

i. Disease and Parasites: High densities facilitate rapid spread, requiring treatments that can pollute water.

ii. Chemical Use: Antibiotics and fungicides can leave residues in fish, posing human health risks

1.19 Conclusion

Aquaculture is vital to Nigeria's food security as fish constitutes a major source of affordable animal

protein, omega-3 fatty acids, vitamins, and minerals for improved nutrition and public health in Nigeria. Nigeria is one of the largest importers of frozen fish in Africa. Expansion of aquaculture reduces reliance on imported fish, conserves foreign exchange, and strengthens the national economy. Aquaculture generates employment for youths and women in both rural and urban areas. Aquaculture can be practiced in pond, cage and tank culture systems. By producing fish under controlled conditions, aquaculture reduces pressure on overfished natural water bodies, supporting sustainable management of Nigeria's aquatic resources. The high market demand for fish in Nigeria makes aquaculture a profitable enterprise that helps reduce poverty.

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