

AQUACULTURE

SYSTEM & TECHNOLOGY

Innovative Systems for Reliable Food Production



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AQUACULTURE

S Y S T E M & T E C H N O L O G Y

**Innovative Systems for Reliable Food
Production**

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P O L I T E K N I K J E L I K E L A N T A N

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Preface

Aquaculture has become an essential contributor to global food production, offering a reliable source of protein and supporting the growth of sustainable industries. As the sector continues to expand, understanding the different types of aquaculture systems is crucial for anyone involved in fish production, research, or farm management. This book, *Aquaculture System and Technology: Innovative Systems for Reliable Food Production*, was developed to provide a clear and practical overview of the main culture systems used today.

The chapters cover key systems such as pond culture, tank and raceway setups, recirculating aquaculture systems (RAS), aquaponics, as well as cage, shellfish, and seaweed culture. Each system is presented with explanations of its basic structure and operating principles associated with its use. The aim is to build a strong understanding of how each system functions and how it contributes to efficient and responsible aquaculture.

This book emphasises practical knowledge, system comparison, and the role of simple technologies in improving production. By offering clear descriptions and applied concepts, it serves as a useful guide for learners, educators, and practitioners seeking to strengthen their foundation in aquaculture systems.

It is my hope that this work will inspire further interest in innovative aquaculture practices and contribute to the development of sustainable and reliable food production in the years to come.

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CHAPTER 1

OVERVIEW OF AQUACULTURE SYSTEM



1.1 Definitions of aquaculture systems

An **aquaculture system** is a structured and managed environment designed for the cultivation of aquatic organisms such as fish, crustaceans, mollusks, and aquatic plants.



It involves the use of tanks, ponds, cages, raceways, or other facilities where water quality, nutritional inputs, and growth conditions are controlled to optimize production, survival, and health of the cultured species.

Aquaculture systems may vary in their design, operational complexity, and level of technological integration, ranging from simple earthen ponds to advanced recirculating aquaculture systems (RAS) that recycle water and use automated monitoring.

The primary goal of an aquaculture system is to produce aquatic products efficiently and sustainably to meet food, commercial, or environmental objectives.

1.2 Classification of aquaculture systems

Aquaculture systems can be classified based on several key criteria, each reflecting the environment, intensity, technology, or integration approach. The major classifications are as follows:

1. By Environment

- Freshwater Systems: lakes or rivers
- Brackishwater Systems: estuarine and coastal areas
- Marine Systems: Offshore

2. By Intensity of Production

- Extensive Systems: Low input, rely on natural food and simple management
- Semi-Intensive Systems: Moderate inputs of feed and management
- Intensive Systems: High density, controlled feeding, and water quality management

3. By Integration Level

- Monoculture: Single species in one system
- Polyculture: Multiple species cultured together
- Integrated Multi-Trophic Aquaculture (IMTA): Different trophic levels, e.g., fish, shellfish, and seaweed

1.2 Classification of aquaculture systems

4. By Technological Approach

- Traditional Systems: Relying largely on local resources and minimal technology
- Modern Systems: Employing advanced technology such as recirculating aquaculture systems (RAS), biofloc tech, and automation

5. By Target Species Group

- Finfish Aquaculture
- Shellfish Aquaculture
- Crustacean Aquaculture
- Seaweed/Aquatic Plant Culture

1.3 Criteria for system selection

Selecting the appropriate aquaculture system involves careful consideration of several criteria to ensure optimal productivity, sustainability, and economic viability. The key criteria for system selection include:

1. Site Characteristics

- Water quality (temperature, pH, oxygen, salinity)
- Availability and reliability of water supply
- Soil type and topography
- Proximity to markets and infrastructure

2. Target Species

- Biological requirements and tolerance of culture species
- Growth rate, disease risk, and compatibility with system design

3. Production Objectives

- Scale of production (small, medium, large)
- Desired intensity (extensive, semi-intensive, intensive)
- Purpose (commercial, research, subsistence)

4. Economic Considerations

- Initial capital and running costs
- Cost-benefit analysis
- Local availability of feed and inputs
- Market demand and selling price

1.3 Criteria for system selection

5. Technological Capacity and Expertise

- Availability of skilled labor and management
- Access to technical support, training, and extension services
- Level of automation, monitoring, and control required

6. Environmental Sustainability

- Impact on local ecosystems
- Waste management and effluent control
- Compliance with regulations and sustainability standards

7. Legal and Regulatory Framework

- Land and water rights
- Permits and legal constraints
- Certification requirements (e.g., MyGAP)

1.4 Type of water supply

There are several types of water supply sources commonly used in aquaculture systems, each with specific advantages and limitations depending on the system design, target species, and geographical location:

1. Surface Water

- Includes rivers, streams, lakes, reservoirs, and ponds.
- Usually abundant and accessible but may be subject to seasonal variation and risks of contamination from runoff, pollutants, and pathogens.



2. Groundwater

- Sourced from wells or boreholes tapping underground aquifers.
- Typically high quality (stable temperature, low pathogens) but limited by aquifer capacity, pumping costs, and sustainability concerns.

1.4 Type of water supply

3. Rainwater

- Harvested from catchment areas or rooftops and stored in tanks or ponds.
- Clean and free from many contaminants, but volume depends on local rainfall patterns and storage capacity.



4. Municipal Water

- Treated and supplied by city/town water utilities.
- Reliable and consistent quality, although expensive and sometimes high in residual chlorine, which may require removal before use.

1.4 Type of water supply

5. Seawater

- Used in marine aquaculture systems, sourced directly from the ocean or through pipelines.
- High salinity suitable for marine species; requires monitoring for biosecurity, pollutants, and temperature.

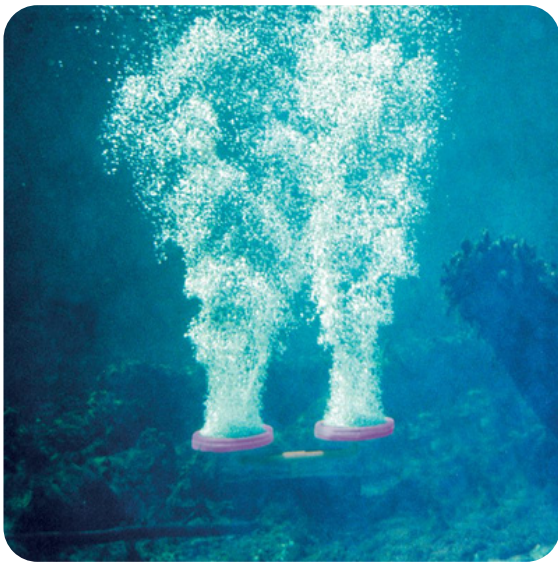


6. Brackish Water

- Combination of freshwater and seawater, usually found in estuaries or artificially mixed.
- Suitable for species adapted to intermediate salinity; needs careful management of mixing and quality.

1.5 Aeration and oxygenation equipment

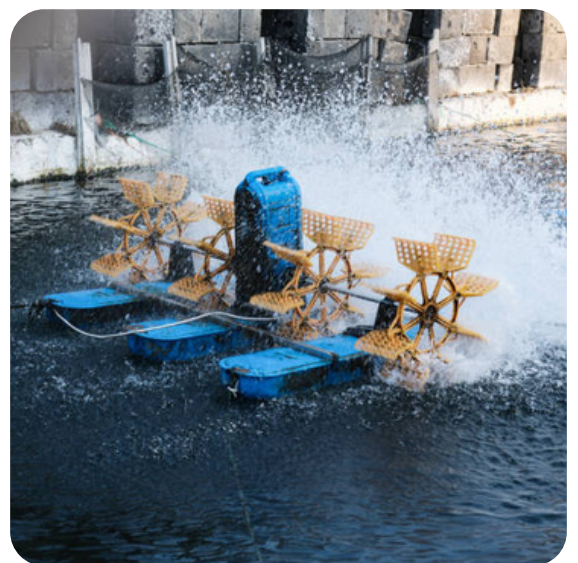
Aeration and oxygenation equipment are essential components in aquaculture systems, responsible for maintaining adequate dissolved oxygen levels in water, which is vital for the health, growth, and survival of aquatic organisms. The main type of equipment as follows:



1. Diffused Air Systems

- Use air blowers or compressors to push air through diffusers (stones/discs/tubes) that release bubbles into water, increasing gas exchange efficiency.
- Commonly used in tanks, ponds, and recirculating aquaculture systems (RAS).

- Mechanical devices like paddlewheels, propellers, or fountains agitate the water surface to increase oxygen transfer from the atmosphere.
- Effective for large ponds and raceways.



2. Surface Aerators

1.5 Aeration and oxygenation equipment



3. Subsurface Aerators

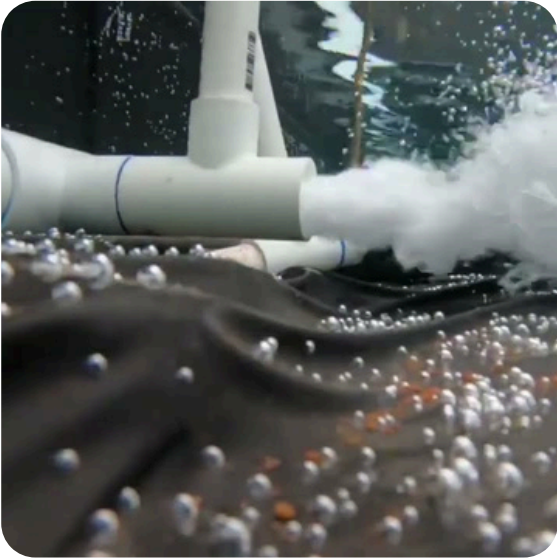
- Devices such as airlift pumps or submerged turbines create water movement and mixing at depth, which improves oxygen distribution.

- Specialized equipment that injects pure oxygen into pressurized water, achieving high saturation levels. Widely used in intensive or high-density systems.



4. Oxygen Cones and Saturators

1.5 Aeration and oxygenation equipment



- Utilize pressure differences to mix air or pure oxygen with water as it flows through pipes, increasing dissolved oxygen.

5. Venturi Injectors

- Storage and controlled dosing of liquid oxygen (LOX) for large-scale or emergency oxygenation, especially in hatcheries or superintensive production.



6. Liquid Oxygen Systems

Benefits and Functions:

- Maintains optimal oxygen levels to prevent stress, disease, and mortality.
- Improves water quality by facilitating waste breakdown and preventing stagnation.
- Supports higher stocking densities and faster growth rates.
- Allows rapid response to environmental fluctuations or emergencies.

CHAPTER 2

LAND BASED SYSTEM



2.1 Overview of Land Based System

A land-based system in aquaculture refers to the cultivation of aquatic organisms, such as fish, crustaceans, mollusks, or aquatic plants, within engineered facilities situated on terrestrial land rather than open water environments.

These systems utilize ponds, tanks, raceways, or recirculating setups, where water quality, temperature, and other environmental parameters can be carefully controlled for optimal growth and health of the cultured species.

Land-based aquaculture systems offer distinct advantages such as enhanced biosecurity, reduced risks from environmental hazards (storms, pollution, predators), and greater management of production inputs and waste. They are adaptable to a wide variety of species and production intensities, ranging from simple earthen ponds to sophisticated recirculating aquaculture systems (RAS).

These systems contribute significantly to global aquaculture production, allowing for intensive culture, year-round operation, and the possibility of locating facilities close to urban centers, reducing transport times to market.

2.2 Earthen pond system



Figure 2.2: The structure of earthen pond system

An aquaculture earthen pond system is one of the oldest and most widely used land-based methods for cultivating aquatic organisms, such as fish, shrimp, or aquatic plants. The system consists of ponds constructed by excavating or building dikes from native soil, forming shallow basins that retain water and provide an environment for the cultured species.

Structure and features of earthen pond

Shape and Size

Earthen ponds can be rectangular, square, or irregular in shape, depending on the topography and available land. Sizes may vary from small experimental ponds to several hectares for commercial production.



Dikes/Bunds:

Raised earth embankments (dikes) are built around the perimeter to contain water. The dikes are often compacted to prevent seepage and erosion.

Inlet and Outlet Structures:

Pipes, canals, or sluices facilitate controlled water inflow and outflow, enabling water exchange and maintaining water quality.



Structure and features of earthen pond

Bottom Preparation:

The pond bottom is graded to allow for proper drainage and easy harvesting. Sometimes it is lined with clay or other impermeable materials to minimize water loss.



Operation and management

Water supplies :

The pond bottom is graded to allow for proper drainage and easy harvesting. Sometimes it is lined with clay or other impermeable materials to minimize water loss.

Stocking:

Fish fry, fingerlings, or shrimp postlarvae are introduced at densities appropriate for the species and desired production intensity.

Feeding:

Depending on the production system (extensive, semi-intensive, intensive), fish may feed on natural pond productivity (algae, plankton) or supplemented with commercial feeds

Structure and features of earthen pond

Aeration and Mixing:

While ponds depend on natural oxygen diffusion from wind and photosynthesis, mechanical aerators or pumps may be used, especially for high stocking densities.

Water Quality Management:

Regular monitoring of temperature, dissolved oxygen, pH, and waste metabolites (ammonia, nitrite) is crucial to maintain a healthy environment.

Harvesting:

Ponds are partially or completely drained, and the stock is collected using nets or trap structures.

2.3 Tank system



Figure 2.3: The structure of tank system

A tank system in aquaculture refers to the cultivation of aquatic organisms in engineered water-holding structures made from concrete, fiberglass, plastic, or metal. It offers a controlled environment for intensive rearing of fish, crustaceans, mollusks, and aquatic plants. Tank systems can be stand-alone or integrated into recirculating aquaculture systems (RAS), hatcheries, research facilities, or commercial operations.

Structure and features of tank system

Tank Material:

Tanks are commonly constructed from concrete, fiberglass, plastic (polyethylene or PVC), or metal. Choice of material depends on intended use, durability, and cost.

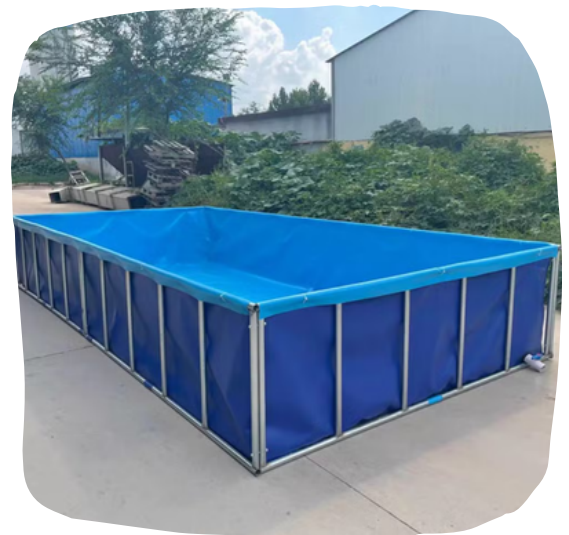


Shape and Size:

Tanks may be circular, oval, rectangular, or raceway (elongated channels). Circular tanks promote efficient mixing and self-cleaning due to circular flow, while rectangular tanks are easier to construct and maintain.

Volume Capacity:

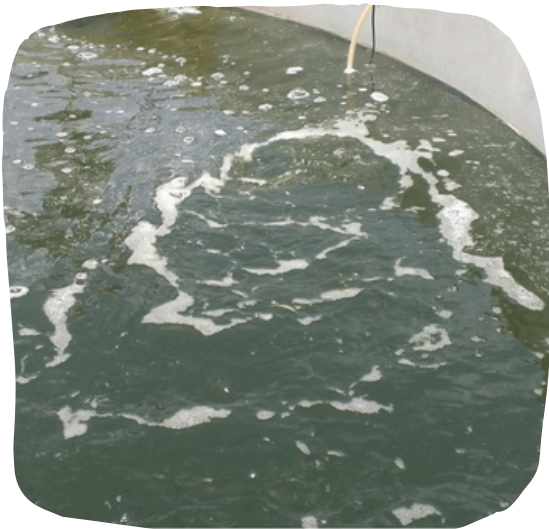
Sizes can range from a few hundred liters for laboratory use to tens of thousands of liters for commercial production.



Structure and features of tank system

Water Inlet and Outlet:

Inlet pipes deliver fresh water, typically positioned to promote circulation. Outlet structures allow regulated removal of water, waste, and facilitate harvest.



Aeration and Oxygenation:

Diffuser pipes, air stones, or oxygen injectors are used to maintain dissolved oxygen. Mechanized mixing ensures even distribution.

Structure and features of earthen pond

Operation and management

Water Quality Control:

Water temperature, pH, dissolved oxygen, ammonia, nitrite, and other parameters are closely monitored. Water can be treated, recirculated, filtered, or regularly replaced to maintain a healthy environment.

Stocking:

High-density stocking is possible due to close environmental control. Species commonly reared include tilapia, catfish, trout, shrimp, and ornamental fish.

Feeding:

Precision feeding with formulated pelleted diets is common. Automatic feeders may be used for consistent schedule delivery.

Waste Removal and Filtration:

Solids and dissolved wastes are managed using mechanical filters, biofilters, settling tanks, and periodic water exchanges. RAS designs incorporate advanced filtration and disinfection to allow continual reuse of water.

Health Management:

Disease prevention is facilitated by biosecurity practices, including quarantine, sanitation, and monitoring.

Harvesting:

Fish can be easily collected using nets as water levels are lowered or tanks drained.

2.4 Raceway system



Figure 2.4: The structure of raceway system

A raceway system in aquaculture is a type of land-based, flow-through culture system designed for the intensive rearing of fish and other aquatic species. It consists of long, narrow, shallow channels (raceways) constructed from concrete, fiberglass, or polyethylene, through which water continuously flows, providing optimal conditions for growth, waste removal, and oxygenation.

Structure and features of raceway system

Raceway Shape and Size:

Raceways are typically long rectangular channels, measuring several meters in length and 1–3 meters in width and depth. Multiple raceways may be arranged side by side for large-scale operations.

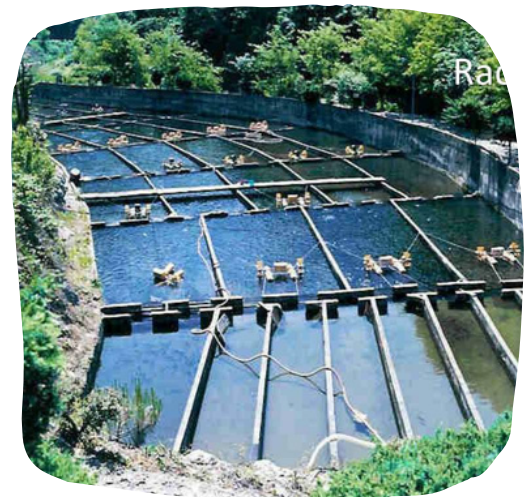


Material:

Most raceways are built from reinforced concrete for durability, but fiberglass or polyethylene variants exist for smaller or mobile setups.

Water Flow Design:

Water enters at one end of the raceway and exits at the other, usually aided by gravity or pumps. This unidirectional flow ensures continuous removal of metabolic wastes while supplying fresh, oxygen-rich water.



Structure and features of raceway system

Inlet and Outlet Structures:

Inlet pipes, channels or diffusers introduce water, while outlets often have screens or weirs to prevent fish escape and facilitate harvest.



Aeration and Mixing:

Oxygen levels are maintained using diffused aeration pipes, paddlewheel aerators, or by cascading water at inlets. Water movement also keeps waste particles suspended and directed toward outlets.

Structure and features of raceway system

Operation and management

Stocking Density:

Raceway systems support high-density stocking, usually for fast-growing freshwater fish such as trout, tilapia, and catfish. Stocking rates are adjusted based on water flow and carrying capacity.

Feeding:

Fish are fed formulated diets delivered manually or via automatic feeders along the raceway length.

Water Quality and Filtration:

Continual water exchange keeps ammonia, nitrite, and solid wastes at low levels. In intensive setups, effluent may be treated with settling tanks, biofilters, or passed through wetlands before discharge.

Health Monitoring:

Regular observation and sampling allow for disease prevention and rapid response due to the accessibility and controlled environment.

Harvesting:

Fish can be easily concentrated and collected at the outlet end with nets once raceways are partially drained.

2.5 Recirculating aquaculture system (RAS)



Figure 2.5: The structure of recirculating aquaculture system (RAS)

A Recirculating Aquaculture System (RAS) is an advanced, land-based aquaculture system that continuously reuses and treats water, keeping it in a closed loop to provide optimal conditions for raising fish, shrimp, or other aquatic organisms. RAS technology allows for intensive production in limited space, precise control of water parameters, and minimal environmental impact compared to traditional flow-through systems.

Structure and features of recirculating aquaculture system

Culture Tanks:

Fish or other aquatic animals are raised in specialized tanks made from concrete, fiberglass, or plastic. Tanks can be circular or rectangular, sized according to stocking density and species requirements.



Mechanical Filtration:

Removes suspended solids and particulates from water via drum filters, screen filters, or settling tanks.

Biofiltration:

Uses specially designed biofilter media (trickling filters, moving bed filters) where beneficial bacteria convert toxic ammonia (from fish waste) to less harmful nitrate through nitrification.



Structure and features of recirculating aquaculture system

Aeration & Oxygenation:

Air stones, oxygen cones, or venturi injectors maintain high dissolved oxygen levels. Pure oxygen supplementation is used for high-density systems.



Degassing Units:

Remove excess carbon dioxide and nitrogen gas, and stabilize pH.

UV/ Ozone Disinfection:

Ultraviolet or ozone units kill pathogens and maintain biosecurity, reducing the risk of disease outbreaks



Structure and features of recirculating aquaculture system

Pumps and Water Movement:

Circulation pumps keep water moving through the system, ensuring even distribution and regular exposure to filtration units.



Heating/Cooling Systems:

Temperature control via heat exchangers or chillers keeps conditions optimal for specific species and production goals.

Structure and features of recirculating aquaculture system

Operation and management

Water Reuse:

Up to 95–99% of water is continuously recycled, reducing freshwater requirements and minimizing discharge.

Stocking Density:

High stocking rates are possible due to precise water quality control; yields per unit area/volume far exceed traditional systems.

Monitoring:

Constant tracking of water parameters (temperature, pH, dissolved oxygen, ammonia, nitrite, nitrate, carbon dioxide) using sensors and automation.

Feeding & Growth:

Precision feeding using automatic feeders tailored to fish species and growth stages; waste from uneaten feed is quickly removed by system design.

Biosecurity:

Physical barriers, disinfection, and strict protocols protect against disease entry and spread.

Harvesting:

Fish are easily collected with minimal stress; harvest water can be isolated and treated separately.

2.6 Canvas system

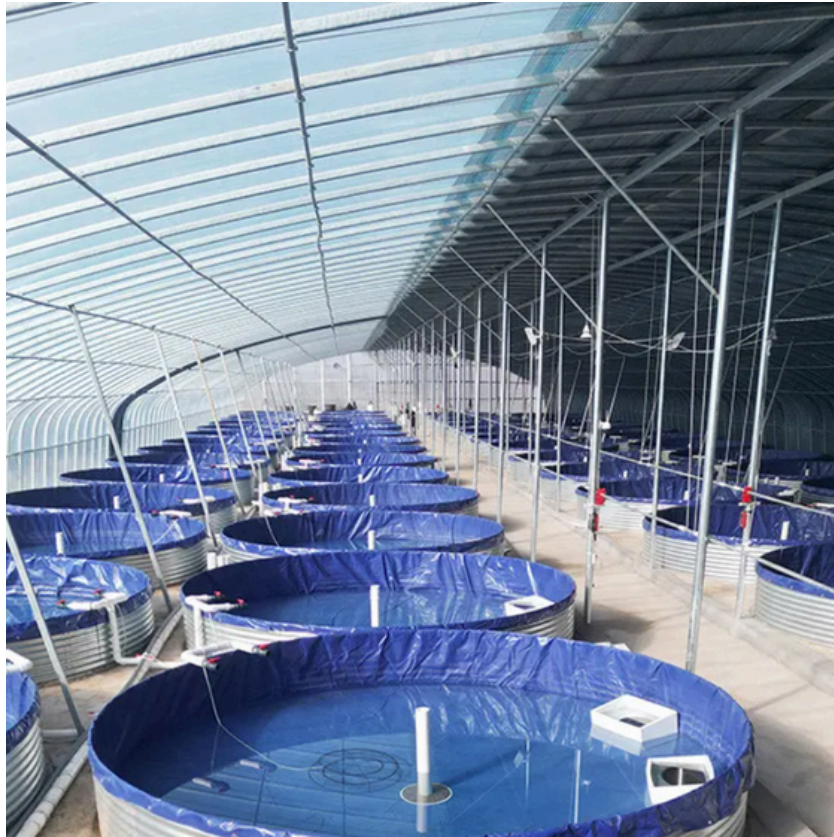


Figure 2.4: The structure of canvas system

A canvas system in aquaculture refers to the use of portable, flexible tanks lined with canvas (polyvinyl, tarpaulin, synthetic fabrics) for the rearing of fish and other aquatic organisms. These systems cater to small- and medium-scale operations, research activities, backyard or urban aquaculture, and temporary holding needs. Canvas tanks offer mobility, ease of installation, and cost-effectiveness, making them popular for demonstration projects, trials, and settings where permanent infrastructure may not be feasible.

Structure and features of canvas system

Tank Design and Material:

Canvas tanks consist of a sturdy frame (often made from steel, PVC, or bamboo) supporting a waterproof canvas liner. The canvas is UV-resistant, non-toxic for aquatic organisms, and easily cleaned or repaired.



Shape and Size:

Tanks are commonly circular or rectangular, with sizes ranging from a few hundred liters to several thousands, depending on requirements and available space.



Installation:

Tanks can be set up on flat surfaces—concrete slabs, levelled ground, or indoors. Setup requires minimal site preparation and no heavy excavation



Structure and features of canvas system

Water Inlet/Outlet:

Simple plumbing (PVC pipes or taps) controls water entry and drainage. Systems may be connected to recirculating units or used as stand-alone hatchery/grow-out tanks.



Operation and management

Water Quality:

Good water management is vital due to lower water volumes. Filtration can be added using portable biofilters, cartridge filters, or daily water renewal.

Stocking Density:

Suitable for rearing fingerlings, juvenile fish, or even market-size animals, with stocking directly dependent on system size, aeration, and water exchange.

Aeration and Mixing:

Portable air pumps, diffusers, or air stones maintain oxygen levels.

Feeding:

Manual or automated feeders dispense measured amounts of pelleted diets, tailored to species and growth phase.

Harvesting:

Simple nets or partial drainage make harvesting straightforward and low-stress for fish.

2.7 Aquaponic and integrated system



Figure 2.4: The structure of aquaponic system

Aquaponic and integrated aquaculture systems represent innovative approaches to food production that link aquatic animals with plants or other agricultural components in mutually beneficial ways. Aquaponics specifically combines recirculating aquaculture (fish or other aquatic species raised in tanks) with hydroponics (soilless plant culture) in a closed-loop system, where nutrient-rich effluent from the fish is converted by microbes into forms that can be absorbed by plants, and the plants in turn help purify the water before it returns to the fish tanks.

Structure and features of aquaponic and integrated system

Tank Design and Material:

Canvas tanks consist of a sturdy frame (often made from steel, PVC, or bamboo) supporting a waterproof canvas liner. The canvas is UV-resistant, non-toxic for aquatic organisms, and easily cleaned or repaired.



Shape and Size:

Tanks are commonly circular or rectangular, with sizes ranging from a few hundred liters to several thousands, depending on requirements and available space.

Installation:

Tanks can be set up on flat surfaces—concrete slabs, levelled ground, or indoors. Setup requires minimal site preparation and no heavy excavation



Structure and features of recirculating aquaculture system

Operation and management

Water Reuse:

Up to 95–99% of water is continuously recycled, reducing freshwater requirements and minimizing discharge.

Stocking Density:

High stocking rates are possible due to precise water quality control; yields per unit area/volume far exceed traditional systems.

Monitoring:

Constant tracking of water parameters (temperature, pH, dissolved oxygen, ammonia, nitrite, nitrate, carbon dioxide) using sensors and automation.

Feeding & Growth:

Precision feeding using automatic feeders tailored to fish species and growth stages; waste from uneaten feed is quickly removed by system design.

Biosecurity:

Physical barriers, disinfection, and strict protocols protect against disease entry and spread.

Harvesting:

Fish are easily collected with minimal stress; harvest water can be isolated and treated separately.



CHAPTER 3 WATER BASED SYSTEM



3.1 Overview of Water Based System

Water-based systems in aquaculture refer to the cultivation of fish and other aquatic organisms directly within natural water bodies, such as oceans, lakes, and rivers. These systems typically utilize cages, nets, or pens to raise fish in their natural environment, relying on the surrounding water to provide necessary conditions for growth—including oxygen, temperature, and waste removal. Water-based aquaculture has become increasingly popular because it uses existing aquatic resources and often requires less infrastructure and energy compared to land-based systems.

Unlike land-based aquaculture, where fish are farmed in controlled tanks or ponds, water-based aquaculture systems rely more heavily on the condition and quality of the environment. Species like salmon, trout, tilapia, and sea bass are commonly produced using these methods. One main advantage is the scalability and cost-effectiveness, as farmers can utilize large areas of water without extensive construction. They also tend to have lower energy requirements, since heating, aeration, and filtration are provided by natural processes.

Water-based aquaculture systems are exposed to various environmental challenges. Fish in these systems face risks from water-borne diseases, pollution, and changing weather, all of which can negatively affect their health and growth.

3.2 Cage culture system (Floating)



Figure 3.1 (1): The structure of floating cage system

A floating cage culture system is a water-based aquaculture method in which fish or other aquatic organisms are confined and reared in floating enclosures (cages) placed in open water bodies such as lakes, reservoirs, rivers, or coastal areas. This approach allows natural water flow through the cage, supporting high-density culture with relatively low infrastructure requirements.

Structure and features of floating cage system

Cage Frame & Buoyancy:

The cage is constructed with a lightweight, durable frame made from HDPE (high-density polyethylene), PVC, or galvanized steel. Buoyant materials such as plastic drums, foam blocks, or air-filled tubes are attached to the frame to enable flotation on water.



Netting or Mesh:

- The enclosure itself is made from non-toxic, UV-resistant netting or mesh, forming a box, cylindrical, or hexagonal shape. Mesh size is adapted to the cultured species and stocking size.

Anchoring System:

Cages are anchored to the water body floor using ropes, chains, or weights to prevent drift caused by water currents and wind.



Structure and features of floating cage system

Size & Arrangement:

Cage size can range from small units (1–5 m³) for demonstration or experimental culture to huge commercial cages (>500 m³). Cages may be grouped together, forming cage farms.



Operation and management

Stocking:

High stocking rates are possible due to precise water quality control; yields per unit area/volume far exceed traditional systems.

Feeding:

Constant tracking of water parameters (temperature, pH, dissolved oxygen, ammonia, nitrite, nitrate, carbon dioxide) using sensors and automation.

Water Exchange & Quality:

Constant tracking of water parameters (temperature, pH, dissolved oxygen, ammonia, nitrite, nitrate, carbon dioxide) using sensors and automation.

Structure and features of floating cage system

Biofouling Management:

Cage nets are periodically cleaned or replaced to remove buildup of algae, barnacles, or debris that can restrict water flow and oxygen exchange.

Predator Protection:

Nets of suitable strength and design are deployed to prevent entry of predators (birds, wild fish, turtles).

Disease Monitoring:

Due to stocking density and open exposure, regular inspection for disease, parasites, and stress symptoms is necessary; rapid removal of infected stocks helps prevent outbreaks.

Harvesting:

Fish are harvested by netting inside the cage or by raising/lifting the cage structure, concentrating animals for easy access.

3.2 Cage culture system (submersible)



Figure 3.1 (2): The structure of submersible cages system

A submersible cage culture system is an innovative aquaculture approach where fish or other aquatic organisms are grown in cages that can be positioned below the water surface, either at varying depths or fully submerged. This system is designed to take advantage of stable water conditions below the surface, reduce exposure to surface hazards (such as storms, ice, or vandalism), and access cooler, oxygen-rich water layers to optimize fish welfare and productivity.

Structure and features of submersible cage system

Cage Construction:

Submersible cages are typically constructed from robust frames, often of high-density polyethylene (HDPE), stainless steel, or other corrosion-resistant materials that support strong mesh netting designed to withstand water pressure and predator attacks.



Design and Shape:

Cages may be spherical, cylindrical, or box-shaped, with strong netting and reinforced corners/edges. They are built to allow water movement through the enclosure for waste removal and oxygen supply.

Submersion Mechanism:

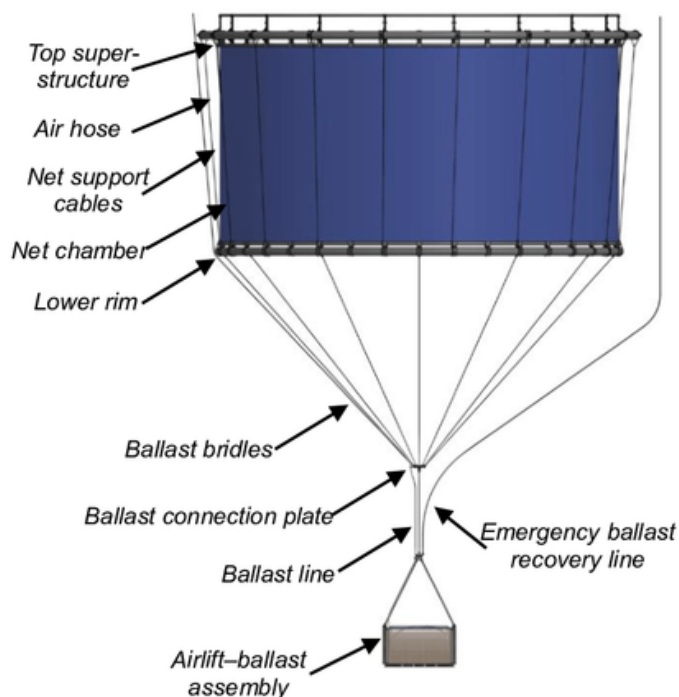
Floating cages can be converted to submersible status or purpose-built with ballast tanks, air bladders, hydraulic winches, or weighted anchors. These mechanisms allow the cage to be lowered or raised in the water column as needed.



Structure and features of submersible cage system

Mooring and Stability:

Anchors and mooring lines attached to the cage and secured to the bottom or floating platforms keep the cage stable in currents, tides, and waves.



Operation and management

Stocking:

Fish are stocked inside at appropriate densities for species and environmental conditions. Typical species include salmon, sea bass, sea bream, cobia, and other marine finfish.

Depth Adjustment:

Cage depth is adjusted seasonally or as needed to avoid adverse surface conditions (storms, heat, algal blooms) or to take advantage of deeper, cooler, and more oxygenated water.

Feeding:

Feeding is accomplished using submerged, automated feeders or delivery systems designed to withstand water pressure and prevent feed loss in currents.

Structure and features of submersible cage system

Monitoring:

Underwater cameras and sensors monitor fish health, behavior, water quality (temperature, oxygen, current), and cage integrity.

Maintenance:

Submersible cages are periodically raised to the surface for cleaning, inspection, and harvesting; underwater cleaning robotic devices may be used for routine maintenance.

Harvesting:

Fish are typically removed by raising the cage towards the surface. Portable nets or pump systems may assist in concentrating and removing the stock.

3.3 Pen culture system



Figure 3.3 : The structure of pen culture system

A pen culture system in aquaculture is a water-based method where aquatic organisms are reared in large, fixed enclosures constructed in natural water bodies such as lakes, reservoirs, rivers, or shallow coastal areas. Pens are designed to utilize the natural environment while still providing some control over the cultured stock. Unlike cages, which are suspended or floating, pens are anchored and generally extend from the water surface to the bottom or are built on firm bases.

Structure and features of pen culture system

Pen Framework:

Pens are typically built using frames made from wood, bamboo, galvanized steel, or HDPE supported by posts anchored in the substrate. For coastal marine pens, concrete or steel pilings may be used.



Netting or Fencing:

Walls are constructed from sturdy netting, mesh, or wire fence that runs from the water surface down to the bottom, enclosing an area for culture but allowing natural water flow.

Shape and Size:

Shapes can be rectangular, square, or circular, depending on site characteristics and target species. Sizes are often larger than cages, varying from several hundred square meters to several hectares.



Structure and features of pen culture system

Base/Foundation:

The bottom of the pen is usually the natural substrate (mud, sand, gravel). In some cases, the area within the pen may be improved by adding sand, gravel, or concrete slabs to ensure suitable conditions.



Open-Top Structure:

Pens are open at the top, with fencing extending above the water surface to prevent escape and exclude predators.

Structure and features of pen culture system

Operation and management

Stocking:

Fish (tilapia, carp, trout, milkfish), shrimp, or mollusks are stocked within the pen at densities suited to the species' behavior, growth requirements, and water body carrying capacity.

Feeding:

Animals may rely partially on natural productivity (plankton, detritus) within the enclosed area. Supplemental feeding is provided to promote rapid growth.

Water Quality Management:

Continuous exchange of water with the surrounding body ensures oxygenation and waste removal. However, water quality can be affected by outside pollution, eutrophication, or algal blooms.

Predator and Escape Control:

Fencing and netting are checked regularly to prevent stock loss and intrusion by wild animals. Structures are designed to withstand waves, storms, and physical damage.

Maintenance:

Periodic cleaning and repair of netting/fencing, especially checking for holes or biofouling buildup.

Harvesting:

Fish are harvested using nets, traps, or partial draining (for pens in shallow waters). Stock is concentrated for collection as needed.

3.4 Raft culture system



Figure 3.3 : The structure of raft culture system

A raft culture system is a specialized open-water aquaculture method used primarily for cultivating shellfish (such as mussels and oysters) and seaweed. In this system, organisms are grown on or attached to structures (rafts) that float on the surface of natural water bodies—coastal areas, bays, or estuaries—allowing them to access nutrient-rich waters with minimal infrastructure and land use.

Structure and features of raft culture system

Raft Construction:

Rafts are usually built from durable, buoyant materials such as bamboo, timber, plastic pipes, or high-density polyethylene (HDPE). The raft consists of a floating frame on which ropes, nets, or trays are suspended vertically into the water.



Buoyancy:

Empty barrels, floats, or foam blocks are fixed to the raft frame to provide consistent buoyancy and stability. The raft's size varies from small single-family frames to extensive commercial installations covering several hectares.

Suspension Lines or Nets:

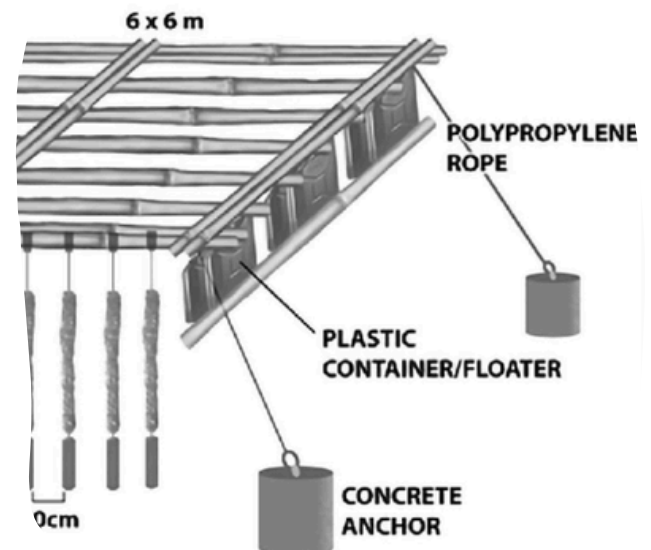
Ropes, strings, or specialized nets/trays hang down from the raft into the water column. Shellfish spat (juvenile oysters, mussels) or seaweed seedlings are attached to these suspension lines.



Structure and features of raft culture system

Anchoring System:

The entire structure is anchored using ropes, chains, or concrete weights to keep the raft stable against wind, tides, and currents.



Operation and management

Stocking:

Spat or seedlings are initially attached to ropes, nets, or trays. For shellfish, juvenile mussels or oysters are glued, sewn, or socked onto lines. For seaweed, seedlings are tied or seeded along ropes and nets.

Growth and Water Flow:

Organisms suspended in the water column are exposed to natural currents, which bring food and nutrients and remove waste. They are protected from predators and sedimentation by the height and location of the raft.

Maintenance:

Periodic cleaning of rafts and suspension lines is performed to remove biofouling (algae, barnacles, debris). Adjustments are made to lines as stock grows to ensure optimal spacing and access to nutrients..

Structure and features of raft culture system

Monitoring:

Water quality, temperature, and growth rates are closely monitored, especially for commercial operations.

Harvesting:

Mature shellfish or seaweed are removed by lifting ropes/nets/trays onto the raft or a vessel for processing.

3.5 Long line culture system



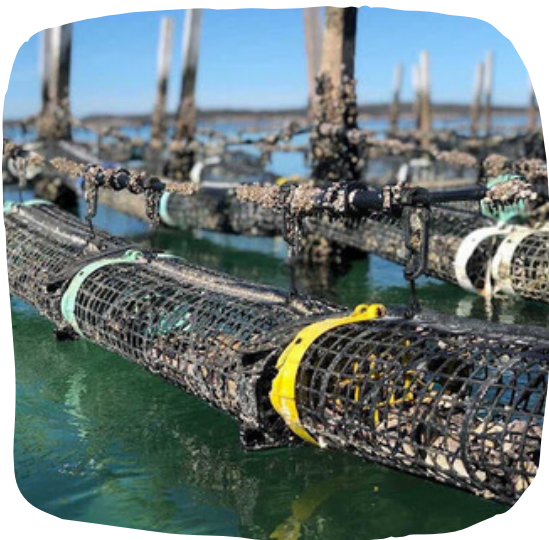
Figure 3.4: The structure of long line culture system

A long line system is an open-water aquaculture technique primarily used for the cultivation of shellfish such as mussels, oysters, and scallops, as well as seaweeds. This method involves suspending ropes, lines, or nets horizontally in the water column between floating buoys or anchored structures, allowing the cultured organisms to grow attached to these lines in nutrient-rich, natural environments such as coastal bays, estuaries, or offshore sites.

Structure and features of long line culture system

Main Long Line:

The central component is a strong rope or line (often made of polypropylene or other marine-grade material) that is stretched horizontally in the water between two anchor points, buoys, or support structures. Lengths may vary from tens to hundreds of meters, depending on site conditions and production goals.



Buoyancy and Anchoring:

Floats or buoys are attached to the long line at intervals to keep it suspended at the desired depth. Anchors (concrete blocks, screw anchors, or weights) are placed at each end and sometimes at intervals along the line to provide stability against currents, tides, and wave action.

Structure and features of long line culture system

Dropper Ropes or Nets:

Vertical ropes, nets, or trays—known as droppers—are suspended from the main long line. Spat (juvenile shellfish) or seaweed seedlings are attached to these droppers, where they grow as they filter feed from the surrounding water.



Arrangement and Scalability:

Multiple long lines are typically deployed in parallel, forming extensive underwater farms. The layout allows optimal water flow and access to nutrients, supporting high-density production.

Structure and features of long line culture system

Operation and management

Stocking:

Juvenile shellfish or seaweed are attached to droppers by gluing, clipping, or tying, depending on species. Initial placement ensures proper spacing for growth and access to water movement.

Growth Management:

Organisms grow by filtering naturally available food and nutrients from the water. Regular monitoring is essential for assessing growth rates, density, biofouling, and condition.

Maintenance:

Dropper lines and main lines require regular cleaning to remove biofouling (barnacles, seaweeds, debris) that can restrict growth or damage equipment. System integrity and anchoring are checked routinely.

Predator and Poaching Protection:

Regular inspection helps prevent predation (by starfish, crabs, birds) and theft, especially in exposed, easily accessible sites.

Harvesting:

Mature shellfish or seaweed are lifted directly from the droppers for collection and processing. Harvesting can be done manually or with mechanical winches and boats.

3.6 Rack culture system



Figure 3.6: The structure of rack culture system

A rack system in aquaculture is a water-based cultivation method, primarily utilized for farming bivalve mollusks such as oysters, clams, and scallops. This approach involves placing shellfish on structured platforms (racks) that are installed in intertidal or subtidal zones of coastal areas, estuaries, or lagoons. The rack system raises shellfish above the seabed or substrate, optimizing access to clean water flow, food, and reducing risks from predators and sedimentation

Structure and features of long line culture system

Frame Construction:

Racks are constructed using robust, non-corrosive materials such as wood, bamboo, HDPE, or galvanized steel. The design comprises horizontal frameworks supported by legs or posts that are embedded into the substrate.



Supporting Platforms:

Mesh trays, baskets, or shelves are placed on the framework, providing surfaces for shellfish to grow. In some methods, strings, nets, or socks may be suspended from the racks to hold the cultured animals.

Site Selection:

Installed in areas with appropriate tidal range, water quality, and accessibility for management and harvest.



Structure and features of long line culture system

Height and Placement:

Racks are raised above the substrate, typically 0.5–1 meter high, depending on site tide levels and wave action. Placement takes into account optimal water coverage during tidal cycles.



Operation and management

Spat/Seed Placement:

Juvenile shellfish (spat) are placed on trays, baskets, or attached to ropes on the racks. Proper spacing and density ensure adequate growth and access to planktonic food.

Tidal Exposure:

The rack system exploits natural tides: during high tide shellfish are covered with water for feeding and growth; during low tide they are exposed, which can reduce fouling and predation and allow for handling.

Maintenance:

Trays, baskets, and the rack framework require regular cleaning to remove biofouling and debris. Inspection for damage from weather, waves, or predators is essential.

Structure and features of long line culture system

Predator and Pest Management:

Elevation helps protect shellfish from benthic (seafloor) predators (such as crabs and starfish). Nets or protective covers may be added for additional protection.

Monitoring and Growth:

Regular monitoring of shellfish for growth rates, health, and environmental conditions ensures optimum yields.

Harvesting:

Mature shellfish can be easily collected from trays or baskets during low tide, using minimal equipment.

3.7 Crab culture system



Figure 3.7: The structure of crab culture system in individual box

An individual box crab culture system is an intensive method where each crab is kept separately in its own perforated container, usually arranged in racks or vertical “crab apartments” and connected to a pond, flow-through, or recirculating aquaculture system (RAS). This design is mainly used for mud/soft-shell crab production to prevent cannibalism, allow close monitoring of molting, and achieve high survival and product quality.

Structure and features of crab culture system

Materials:

The culture units are small plastic or HDPE boxes or trays (often around 40–45 × 30–35 × 15–20 cm) with many perforations or slits on the sides and bottom to allow water exchange.



Box arrangement:

Boxes are mounted in multi-tier racks, pontoons, or vertical “condo” frames; a typical module may contain 50–100 boxes per rack and hundreds to thousands of boxes per system.

Compartment:

Each compartment holds a single crab at a density of 1 crab/box so they cannot fight or damage each other, which is critical during moulting.



Structure and features of crab culture system

Water supply:

Water is supplied either from a nearby pond or from an indoor RAS using pumps, piping, and distribution manifolds so that all boxes receive continuous or frequent flow of clean, aerated brackish water.



Filtration system:

The RAS version includes mechanical filtration, biofilters, protein skimmers, and UV or ozone units to maintain good water quality (dissolved oxygen >5 mg/L, pH 7.5–9, salinity roughly 15–25 ppt, low ammonia and nitrite).

Facilities:

Facilities are usually roofed or located indoors to protect crabs and equipment from sun, rain, and predators, and to stabilize temperature.



Structure and features of crab culture system

Operation and management

Spat/Seed Placement:

Seed crabs (typically 50–150 g for soft-shell production or lean adults for fattening) are acclimated to system salinity and temperature, graded by size, and stocked one per box.

Feeding management:

Crabs are fed once or twice daily with chopped trash fish, mollusks, or formulated feeds; feed quantities are carefully controlled and uneaten feed is removed to avoid water pollution.

Water quality:

Water quality is managed by continuous recirculation and periodic partial exchange; operators monitor temperature, salinity, dissolved oxygen, pH, and nitrogen compounds at least daily, with strong aeration and backup power to avoid hypoxia.

Soft shell production:

For soft-shell production, staff inspect boxes frequently (often every 2–4 hours) to detect freshly molted crabs; these are removed immediately while the shell is still soft, rinsed, and chilled or frozen to preserve quality and prevent hardening.

Structure and features of crab culture system

Biosecurity:

Mortalities, injured crabs, or weak individuals are removed promptly, and boxes are cleaned regularly to prevent biofouling and disease buildup

Harvesting:

A full fattening cycle may last about 2–4 weeks, while continuous soft-shell operations run in batches so some boxes are always in the moulting phase and can be harvested daily or weekly.



CHAPTER 4 EMERGING AND HYBRID TECHNOLOGY



4.1 Overview of emerging and hybrid technology

Emerging and hybrid technologies in aquaculture systems focus on making fish and seafood farming more productive, resource-efficient, and environmentally sustainable. These innovations combine advanced engineering, biology, and digital tools to overcome limitations of traditional ponds and cages, especially issues related to water use, waste, disease, and climate variability.

Modern systems such as advanced Recirculating Aquaculture Systems (RAS), biofloc technology (BFT), and aquaponics allow producers to control water quality very precisely, greatly reduce water consumption, and operate at high stocking densities in small areas. At the same time, digital aquaculture tools—sensors, Internet of Things (IoT) networks, automation, and artificial intelligence—are increasingly used to monitor oxygen, pH, temperature, and fish behavior in real time, enabling data-driven feeding, aeration, and health management.



4.1 Overview of emerging and hybrid technology

Hybrid systems deliberately combine more than one technology or trophic level to capture the strengths of each approach and minimize weaknesses. Examples include RAS-biofloc hybrids, which use both mechanical filtration and microbial flocs to recycle nutrients; aquaponics that link fish tanks with hydroponic crops; and Integrated Multi-Trophic Aquaculture (IMTA), where finfish are co-cultured with shellfish and seaweeds that naturally absorb organic and inorganic wastes. These hybrid and integrated designs increase nutrient recycling, diversify farm products, and help reduce the environmental footprint of aquaculture while supporting long-term food security goals

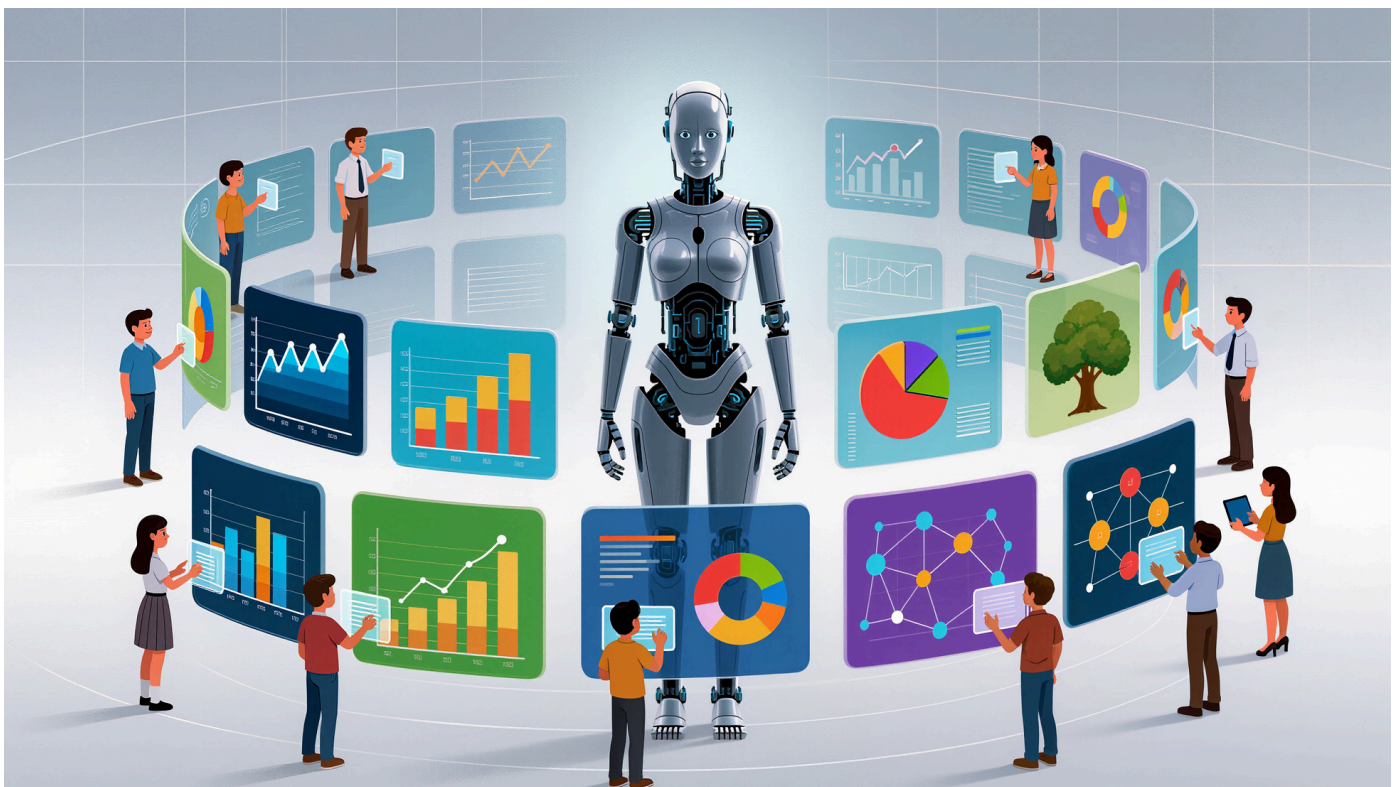


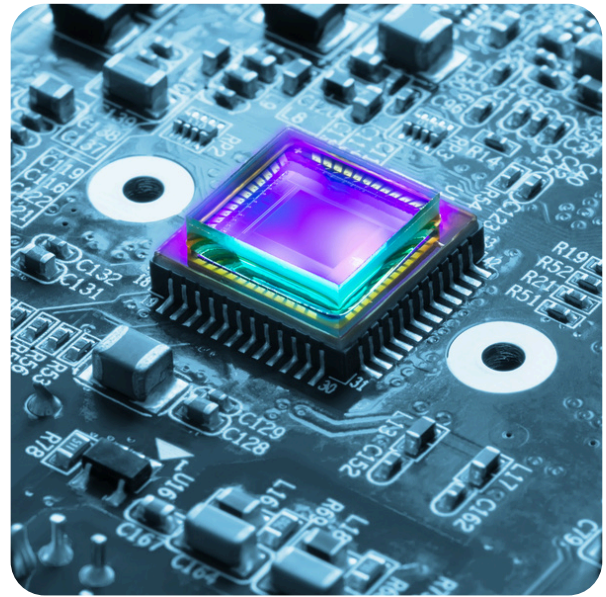
Figure 4.1: Application of artificial intelligence and internet of things in aquaculture system

4.2 IoT-enabled monitoring

IoT-Enabled Monitoring for Smart Aquaculture Systems

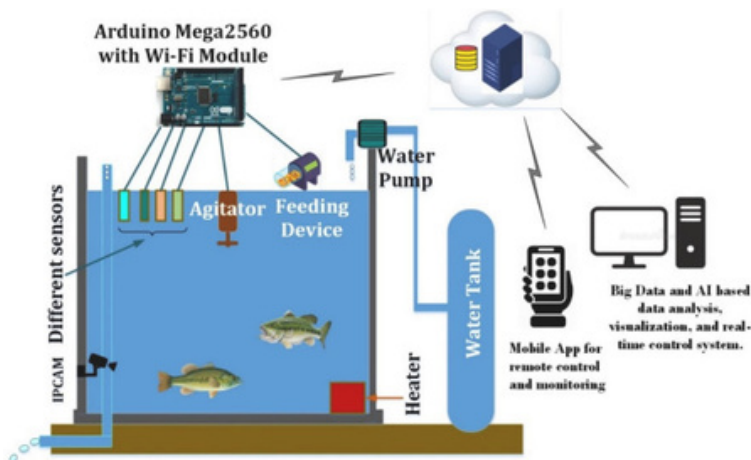
Sensor system

- Water-quality sensors: temperature, dissolved oxygen, pH, salinity, turbidity, ammonia, nitrite.
- Environmental sensors: weather (rain, wind), light, air temperature and humidity around ponds/tanks.
- Biomass/behaviour sensors: cameras, sonar or load cells to estimate fish activity and biomass.



Edge/field devices

- Microcontrollers and gateways (e.g., Arduino, ESP32, Raspberry Pi) collecting sensor data.
- Local data logging and basic processing (filtering, averaging, threshold checks)



4.2 IoT-enabled monitoring

Communication network

- Wireless modules: Wi-Fi for short range; GSM/4G/5G for remote farms; LoRa/LoRaWAN for low-power, long-range links.
- Protocols such as MQTT or HTTP to send data to cloud/servers.



Cloud/platform and data analytics

- Cloud databases and dashboards for real-time visualization on web or mobile apps.
- Analytics tools (statistics, AI/ML) to predict water-quality trends, feed demand, or disease risk.

4.2 IoT-enabled monitoring

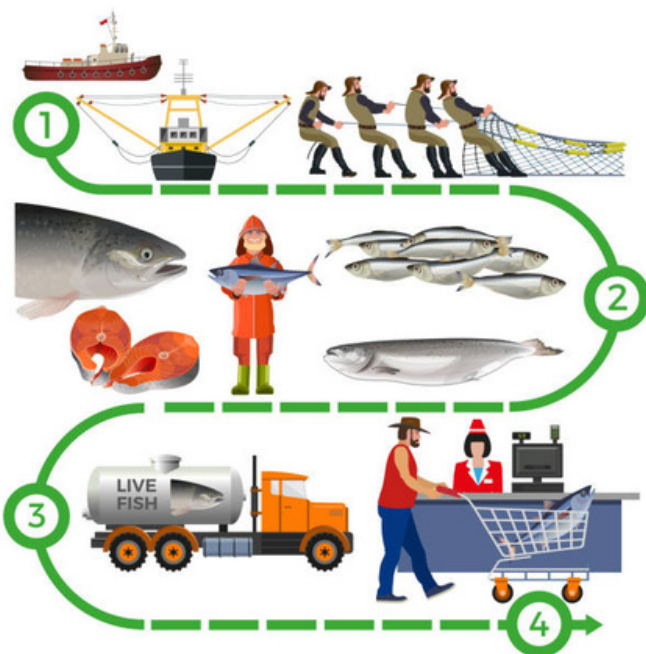
Control and automation system

- Automated aerator, pump, and feeder control based on sensor thresholds or predictive algorithms.
- Alarm/notification system (SMS, app alerts) for critical events like low oxygen or equipment failure.



Farm and value-chain applications

- Smart pond/tank management: reduced mortality, optimized feed conversion, better growth.
- Farm-level sustainability and traceability: integration with record systems and sometimes blockchain for product tracking and certification.



4.3 Automated feeding and water-quality control

Automated feeding and water-quality control in smart aquaculture are usually implemented together, using IoT sensors, controllers, and actuators.

Automated feeding

Smart feeders and hardware

- Use hoppers with screw, belt, or rotating-drum dispensers driven by DC motors or servo motors to release pellets at controlled rates.
- Feeders can be mounted on pond edges, over tanks, on cage walkways, or on feeding barges, sometimes with multiple outlets to cover large areas uniformly.

Control logic and scheduling

- Feeding times and doses are programmed in microcontrollers or PLCs (e.g., Arduino, ESP32, industrial controllers) using fixed schedules or adaptive algorithms.
- Schedules are often linked to fish size, biomass estimates, and water temperature; more advanced systems adjust rations dynamically using historical data and AI/ML models.

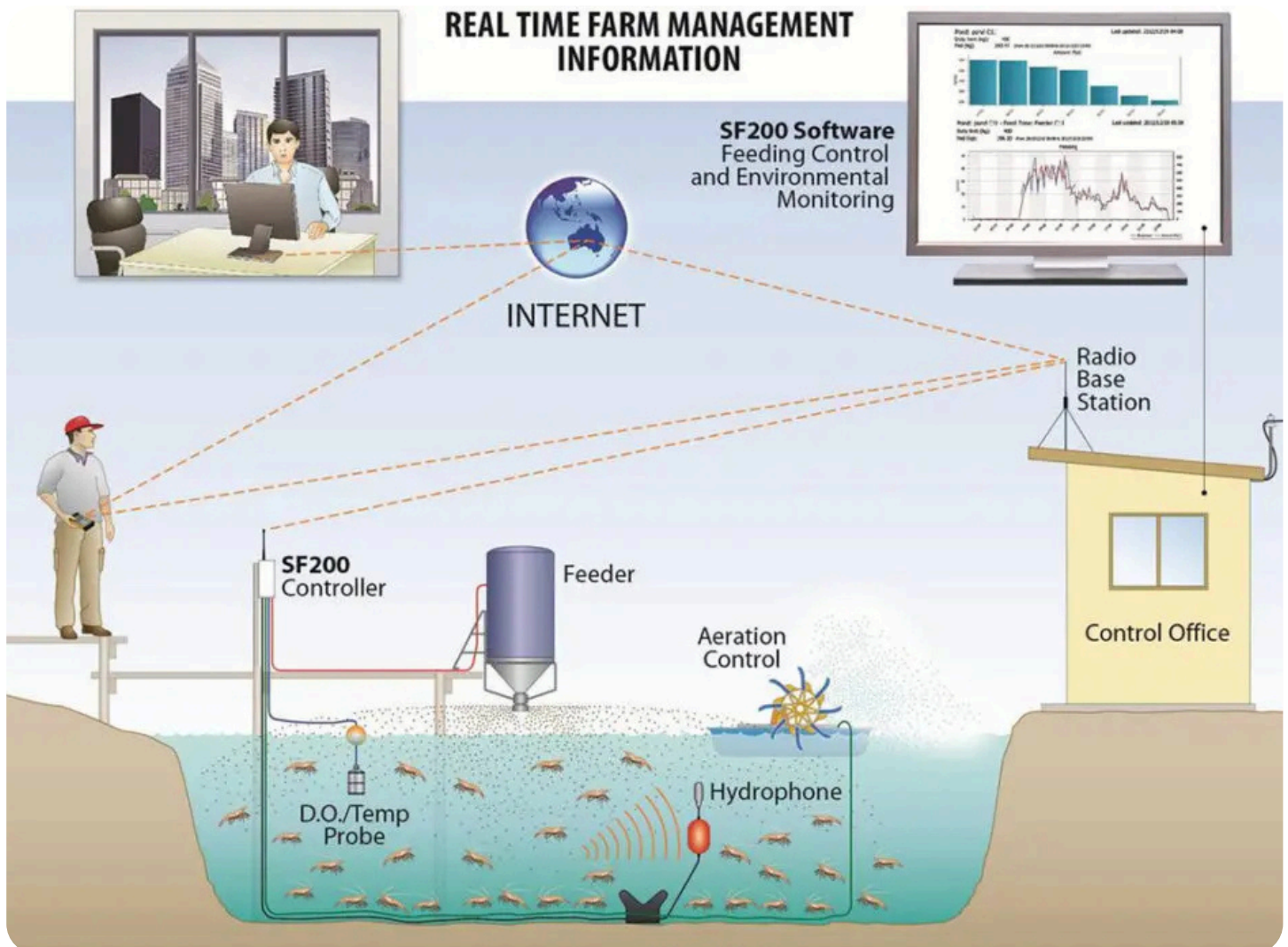
Sensing to optimize feeding

- Systems integrate data from dissolved oxygen, temperature, turbidity, and sometimes cameras or acoustic sensors that infer fish activity or uneaten feed.
- When DO is low, or fish activity drops, the controller can pause or reduce feeding to prevent stress and feed wastage.

4.3 Automated feeding and water-quality control

Benefits

- Improves feed conversion ratio (FCR) and growth by delivering the right amount at the right time while minimizing overfeeding.
- Reduces labor and human error; enables night-time or frequent micro-feeding, which is difficult with manual feeding.
- Lowers environmental impact by cutting excess feed that would otherwise decompose and degrade water quality.



4.3 Automated feeding and water-quality control

Automated water-quality control

Monitoring subsystem

- Multiparameter probes continuously measure temperature, dissolved oxygen, pH, turbidity, salinity and sometimes ammonia or ORP; values are sent to a central controller or IoT gateway.
- Data are logged and visualized on web or mobile apps, with alarms when readings exceed safe thresholds set for the cultured species.

Actuators and control actions

- Aerators and blowers are switched on/off or modulated automatically based on DO set-points, often with nighttime prioritization when oxygen is most critical.
- Pumps and valves control water exchange or recirculation when parameters such as temperature, pH, or turbidity move outside target ranges, bringing in fresh water or activating filtration units.

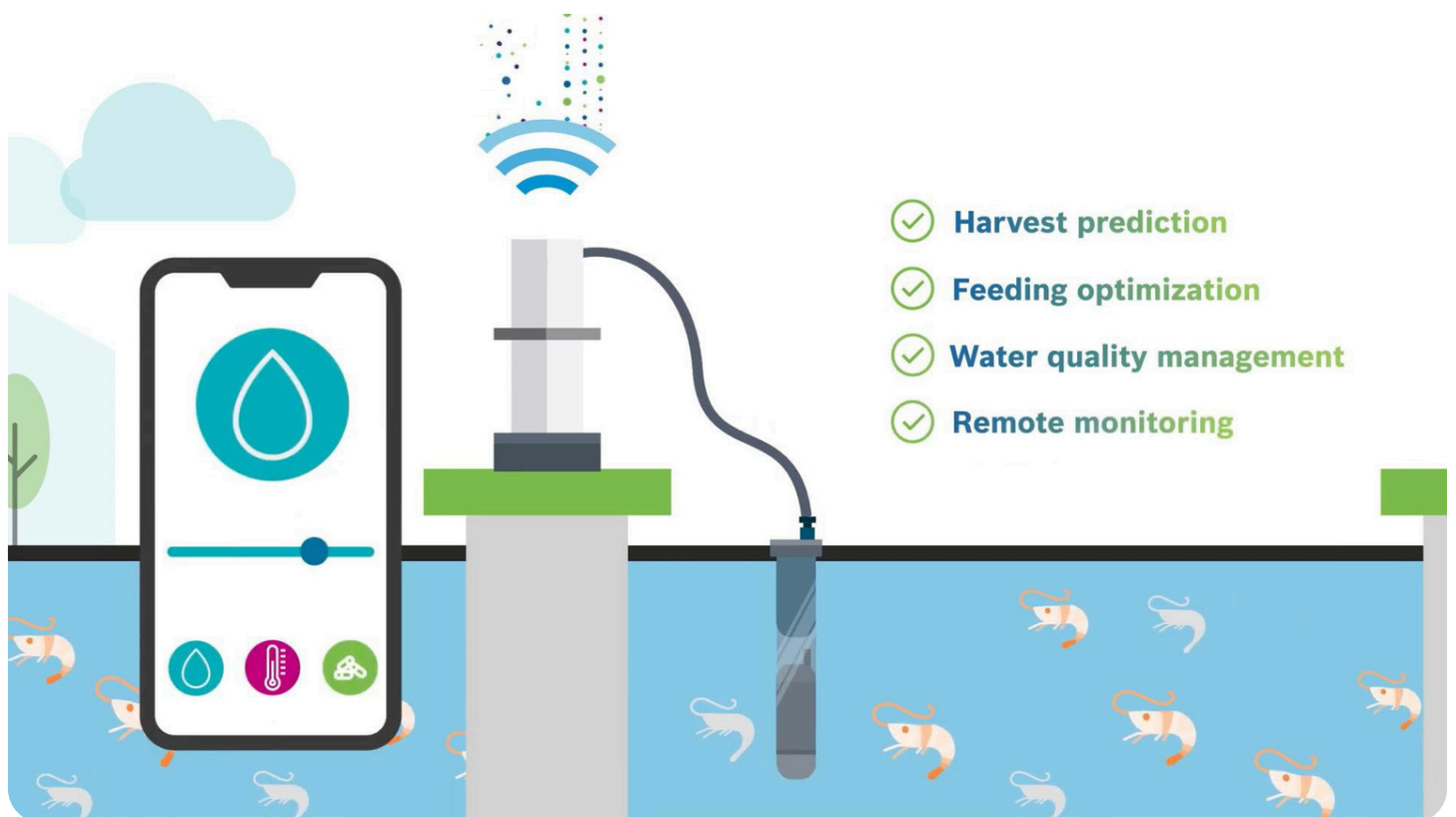
Control strategies

- Simple systems use threshold-based on/off rules (e.g., if DO < 5 mg/L, start aerator; if pH < 6.5, start buffer pump).
- More advanced designs use regression models, fuzzy logic, or machine-learning predictors to anticipate water-quality trends and act proactively rather than reactively.

4.3 Automated feeding and water-quality control

Benefits

- Maintains stable water conditions, reducing stress, disease incidence, and mortality, particularly in high-density ponds and RAS.
- Cuts energy and water costs by running aerators and pumps only when needed instead of 24/7, while still preventing dangerous DO crashes.
- Frees staff from continuous manual checking, allowing larger farms to be managed with fewer people and better documentation for certification and audits.



4.4 AI applications in system optimisation

AI applications in aquaculture system optimisation focus on improving feeding efficiency, predicting and controlling water quality, monitoring fish health, estimating biomass, and supporting farm-wide decision making through data-driven models and decision-support tools.

Feeding optimisation

- Machine-learning and deep-learning models (e.g., random forests, neural networks, reinforcement learning) predict optimal feeding time, ration size, and frequency from data on fish size, behavior, temperature, and water quality.
- Computer-vision systems use underwater cameras to detect appetite (swimming speed, pellet leftovers) and automatically stop or adjust feeders, cutting feed waste and improving FCR by 15–30% in some trials.

Water-quality prediction and control

- AI models forecast key parameters such as dissolved oxygen, temperature, pH, ammonia, and salinity hours in advance, allowing proactive aeration or water-exchange scheduling instead of reactive responses.
- Multivariate ML frameworks rank which water-quality variables drive growth and classify ponds as low, medium, or high-performing, helping farmers focus interventions on the most influential factors.

4.4 AI applications in system optimisation

Fish health, disease, and welfare monitoring

- Computer-vision and deep-learning algorithms (CNNs, RNNs) analyse images and video for abnormal swimming, skin lesions, or color changes, enabling early disease detection and reducing mortality by up to about 20% in reported case studies.
- Anomaly-detection models combine sensor and behavioral data to flag stress events (e.g., impending oxygen crashes, harmful algal blooms) before visible losses occur.

Biomass estimation, growth and harvest planning

- AI processes sonar, stereo-camera, or load-cell data to estimate biomass and growth curves with accuracies often exceeding 90%, supporting precise feed budgeting and optimal harvest timing.

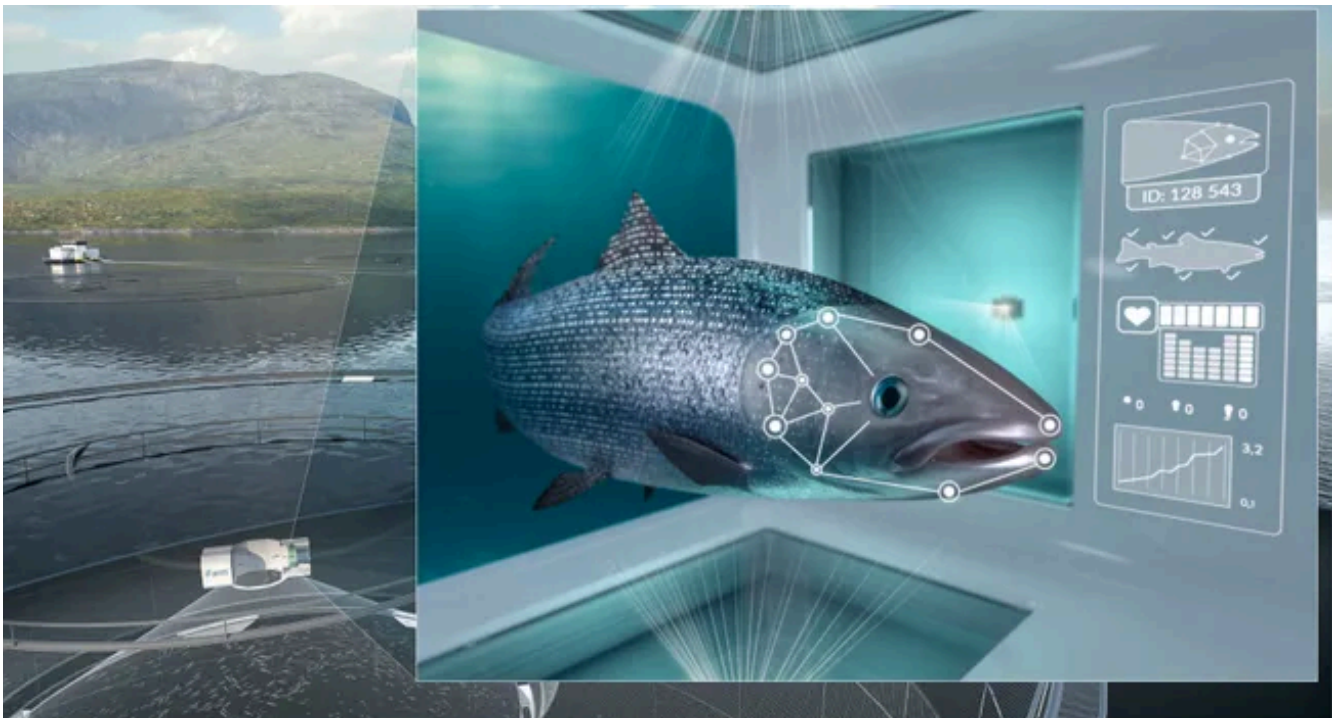
System-level optimisation and decision support

- AI-driven decision support systems integrate IoT sensor data (water quality, feeding, energy use) and recommend or automatically implement actions that balance growth, cost, and environmental impact.
- Optimisation and metaheuristic algorithms (genetic algorithms, swarm intelligence) fine-tune multiobjective trade-offs such as maximizing yield while minimizing energy, water, and feed input across the whole farm.

4.4 AI applications in system optimisation

Supply-chain, forecasting, and risk management

- Time-series and generative AI models forecast demand, prices, and climate-driven risks (storms, temperature anomalies), helping producers schedule stocking and harvest to match markets and avoid losses.
- Combined with traceability platforms, AI analyses production and logistics data to optimise cold-chain routing and verify compliance with sustainability standards.



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